APPLICATION OF HYDROGEL IN PADDY FIELD FOR SOIL MOISTURE RETENTION AND YIELD OPTIMIZATION

Synopsis submitted to CHRIST (Deemed to be University)as

partial requirement for the award of the Degree of

DOCTOR OF PHILOSOPHY

IN

CIVIL ENGINEERING

by

BOREDDY SURYA PRAKASH REDDY

Under the Supervision of

Shibu K Mani
Associate Professor

CHRIST
(DEEMED TO BE UNIVERSITY)
BANGALORE · INDIA

Signature of Scholar

Signature of Supervisor

CENTRE FOR RESEARCH
CHRIST (Deemed to be University)
BENGALURU

MARCH 2022

ABSTRACT

Drought is a perennial global concern that impacts agricultural growth and productivity. Due to insufficient rainfall and uncertainties, crop growth is severely hampered in arid and semi-arid regions. Appropriate water management practices are required for efficient use of soil and water resources. To keep the soil moist after irrigation, organic matter and soil conditioners play a key role. In terms of water stress, India ranks 41st out of 181 countries. India has made quick strides in improving food creation and the nation has turned out to be independent in food creation as well as currently exports to a few different nations also. However, environmental change has risen as a noteworthy risk to India's well-deserved achievement. Dryland covers more than 60% of the region's agricultural land. Also, just 30% of the land receives adequate rainfall.

Effects of climate change or variabilities would get manifested on food production, transportation, storage, and distribution. Rising temperatures, extreme rainfall, outrageous climate conditions, changing soil fertility, and pest infestations are major factors contributing to risk induced agricultural development. Researchers and farmers alike are now looking into the use of hydrogels in agriculture. In order to examine hydrogel qualities for agricultural sustainability, experimental approaches for measuring swelling, retention, slow-release and degradation were used. The effects of hydrogel treatment on numerous crops have been explored over time. Several hydrogel studies reveal considerable improvements in water consumption, crop development, and yield characteristics. A method for assessing hydrogel's viability for agricultural use has been proposed. The study encourages more research towards enhancing hydrogel properties and synthesising it with natural polymers.

The use of hydrogel in agriculture for controlled nutrient release could reduce the environmental impact of fertiliser and pesticide use. Using hydrogel to reduce water footprint in essential crops like rice and wheat could lead to more sustainable irrigation practices. Combining creative ideas with eco-friendly hydrogels can help accomplish sustainable development goals in the coming decades. In water-scarce areas, the hydrogel may be a feasible and cost-effective option for enhancing agricultural productivity. It can be sown directly in the soil or in the nursery plantation's growing medium. The research has found application of hydrogel can effectively been done in paddy cultivation. Experimental results have shown that Rice variety BPT 5204 responded favourably to when hydrogel was applied in soil. Hydrogel application with 40% less water supply had found to be optimum without compromising on the crop yield. Hydrogel application would help the plants to be drought tolerant.

Key Words: Hydrogel, Sustainability, Food, Paddy, Water, Degradation.

TABLE OF CONTENTS

CHAPTER	DESCRIPTION	PAGE NO
-	ABSTRACT	ii
1.	INTRODUCTION	1
2.	EXTENSIVE LITERATURE REVIEW	3
3.	RESEARCH CHALLENGES, GAPS AND LIMITATIONS	6
4.	PROBLEM IDENTIFICATION AND STATEMENT	7
5.	OBJECTIVES	7
6.	TOOLS AND METHODOLOGIES	7
7.	ACCOMPLISHMENT OF RESEARCH WORK (description/analysis/simulation/testing/validation, graphs, tables, figures)	9
8.	RESULTS AND DISCUSSIONS	12
9.	CONCLUSION	16
-	BIBLIOGRAPHY	17
-	PUBLICATIONS	19
-	ANNEXURE (proof of publications)	20

LIST OF FIGURES

S. No	TITLE	PAGE NO
1.	RANDOMISED CONTROL TECHNIQUE (RCT) METHODOLOGY	8
2.	LAYOUT OF EXPERIMENTAL GROUPS FOR COMPARATIVE STUDY IN THE FIELD FOR NDLR07 AND BPT5204.	9
3.	EFFECT OF SEED VARIETIES AND HYDROGEL ON PLANT HEIGHT	10
4.	EFFECT OF SEED VARIETIES AND HYDROGEL ON LEAF AREA INDEX	10
5.	EFFECT OF SEED VARIETIES AND HYDROGEL ON NUMBER OF TILLERS	11
6.	EFFECT OF SEED VARIETIES AND HYDROGEL ON PANICLE LENGTH	12
7.	EFFECT OF SEED VARIETIES AND HYDROGEL ON 1000 GRAIN WEIGHT	12
8.	MEAN STANDARD WEEK-WISE METEOROLOGICAL PARAMETERS DURING CROP SEASON	13
9.	DIAGRAMMATIC PLAN OF PLANT GROWTH STUDY DRIP IRRIGATION SETUP	13
10.	CUMULATIVE FTIR PEAKS OF VARIOUS CROP STAGES	14
11.	MORPHOLOGICAL CHANGES OF SOIL IN VARIOUS CROP STAGES OF PADDY	15

1. INTRODUCTION

Rice is the major food crop of India, and it is responsible for a substantial portion of the country's overall food security. It is a large water-consuming crop, particularly when cultivated using the standard irrigation method, with an average of 3000 litres of water required to produce 1 kg of grain. Some additional elements, such as organic matter and soil conditioners, are applied to the soil after an irrigation event to keep the water in the soil for an extended period. In both natural and synthetic soils, soil conditioners play a crucial role in providing plants with a reservoir of soil water on demand in the upper layers of the soil, where the root systems are most found developing. Hydrogels are superabsorbent materials that can absorb and store a few hundreds of times their own weight in water. In indigenous agriculture, hydrogel is a product that has been designed and produced to increase crop productivity per unit of available water and nutrients, particularly in moisture stressed environments.

Extreme weather events and droughts have been more common in recent decades, as has the frequency of such disasters. A number of research have been carried out to determine how climate change influences precipitation and irrigation patterns. A decrease in groundwater reserves in semi-arid regions and shifts in the spatial distribution of surface water in river-fed irrigation plains have led to the prediction that an increase in irrigation storage will be critical in India if agricultural production is to maintain its current level in the face of increasing demand (Devineni et al., 2013). In recent years, it has been stated that the number of drought occurrences has grown over the past decade, and that the pattern of monsoon rainfall, which accounts for 80 percent of Nepal's total precipitation, has become more irregular since 2000. (Jha et al., 2016). Every year on the African continent has been hotter than the previous year for the past two decades. As predicted by Rosenstock et al. (2018), the climate in Africa would drastically alter by 2080, with a rise in temperature of 4.5 degrees centigrade (degrees Celsius).

Hydrogels improve the quantity of available moisture in the root zone, allowing for longer periods of time between irrigations to be maintained (Johnson et al., 1996). If hydrogels are allowed to dry up, the influence they have on the body is diminished; consequently, irrigation is required to ensure the longevity of hydrogels. Hydrogels can be applied to the soil either by mixing them in or by spraying them on. Hydrogels can be combined with micronutrients and insecticides while being applied with the spray technique.

During frequent droughts, water supplies are reduced, and plant transpiration is more difficult due to a reduced water supply. In addition to temperature increases, climate change causes an increase in droughts, floods, variations in the timing and spatial distribution of rainfall, and soil degradation, resulting in lost agricultural land and saltwater intrusion.

SAPs were applied to soils to assess their soil conditioning capability. Many studies have reported that they exhibit the ability to increase the water-holding capacity of soils by acting as water reservoirs, thereby reducing evaporative loss and increasing the water efficiency of irrigation systems. They may be called micro-reservoirs that offer water security to drought-prone and semi-arid regions.

A simple meta-analysis of existing literature showed that the amount of published works related to the agricultural applications of hydrogel has increased by approximately 5 times, while the overall publications concerning hydrogel have increased by approximately 3 times. The availability of water for rainfed rivers is variable as a result of climate fluctuations, which are influenced by precipitation patterns. The combination of a sustainable water usage approach with alternative farming practices that can contribute to an improved crop production environment makes it necessary to investigate alternative approaches that can assist improve the environment.The most advantageous property of superabsorbent polymers lies in absorbing liquids several hundred times than their body weight and turning them into a gel. Therefore, it will keep or avoid water loss from the soil.

From the literature review, the problem statement and the objectives were formulated. Laboratory and field level experiments were performed to achieve the objectives. Through observations and experience from the preliminary tests, a literature review was conducted simultaneously to refine the problem statement further and understand hydrogel behavior mechanisms. On completion of the laboratory stage, the second stage of the experiments were conducted. The purpose of the field-level experimentation was to understand the feasibility of the study and to evaluate the benefits of the applications on actual conditions of crop growth.

2. EXTENSIVE LITERATURE REVIEW

It is possible that farmers and the general public would incur significant losses if there is an intermittent scarcity of water for crops such as rice. Under normal circumstances, a continuous supply of water is required in order to develop such crops. In semi-arid environments, irrigation systems such as rainfed or canal irrigation systems are used to raise crops such as paddy and wheat, which are frequently found in combination (Devineni et al., 2013). Hydrogel has proven to be an effective water reservoir, and its capacity to dissolve in water and release micronutrients slowly contributes to its ability to absorb micronutrients into the soil for soil enrichment (Jamnongkan and Kaewpirom 2010).

Studies have revealed that, despite these apparent benefits, degradation products can be tailored to consume extra nutrients in the soil at the same time, hence promoting the growth and viability of symbiotic organisms (Devineni et al. 2013). Since then, two decades following his discovery, hydrogel research has been focused mainly on simple, chemically crosslinked networks of synthetic polymers, which have applications mostly in ophthalmic and drug delivery research. Since the pioneering work (Wichterle and Lim, 1960) on crosslinked hydrogels, and because of their hydrophilic character and potential to be biocompatible, hydrogels have been of great interest to biomaterial scientists for many years. The word "hydrogel," according to Lee, Kwon, and Park, dates back to an article published in 1894.

Effect of hydrogel

It exploits the existing water potential by reducing water losses and ensuring better living conditions for vegetation are essential. The possibilities of applying superabsorbent polymers (SAPs) in the agricultural field have become increasingly important and have been investigated to alleviate specific agricultural problems like water stress conditions. The literature on the use of superabsorbent polymer in rice and closely related crops and its effects on growth, yield attributes, nutrient uptake, and consumptive use of water are considered in our research work.

Hydrogel derived from natural polymers

Polymers designed for agricultural or other non-medicinal applications must demonstrate a different set of desirable features than polymers designed for medical applications, some of which have already been discussed in the preceding sections. Aside from that, natural polymers

derived from sources such as pectin, cashew gum, Arabic gum, starch, chitosan, and chitin (mostly polysaccharides) are currently being investigated for their potential application in the preparation of these hydrogels due to the low cost, abundance, and biodegradability of these materials to name a few.

Properties that allow for a gradual release

Uncontrolled agricultural fertilizer, herbicide, and pesticide runoff from soils has been shown to be the most significant contributor to surface water eutrophication and groundwater nitrate enrichment, according to recent research findings. However, it is estimated that between 40 and 70 percent of nitrogen and 50 to 70 percent of potassium are lost through leaching. Plant roots are not capable of absorbing large amounts of nutrients.

(Heldeney Rodrigues Sousa et al., 2021) published an article titled "Superabsorbent Hydrogels Based to Polyacrylamide/Cashew Tree Gum for the Controlled Release of Water and Plant Nutrients". Hydrogels are three-dimensional polymeric networks that can retain a large amount of water and maintain their structural integrity. Superabsorbent hydrogels based on polyacrylamide, natural cashew tree gum (CG) and potassium hydrogen phosphate (PHP) were developed as fertilizer and water releaser. The structure, morphology, thermal stability and chemical composition of samples of polyacrylamide and cashew tree gum hydrogels with the presence of fertilizer (HCGP) and without fertilizer (HCG) were investigated, using X-ray diffractometry (XRD), Fourier Transformed Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), Thermogravimetric Analysis (TGA/DTG) and Energy Dispersive Spectroscopy (EDS). The results showed that PHP incorporation in the hydrogel favored the crosslinking of chains. This increased the thermal stability in HCGP but decreased the hardness and adhesion properties.

(Huiyuan Luo et al., 2021) results show that an increase in amylopectin content is beneficial to improve the grafting ratio of acrylamide (AM). The interaction between the AM grafted on amylopectin and amylose molecules through hydrogen bonding increases the pores of the gel network and thins the pore walls. When the amylopectin content was 70%, the water absorption (swelling 45.25 times) and water retention performance (16 days water retention rate 44.17%) were optimal. The effects of different amylose/amylopectin ratios on starch hydrogels' microstructure and water retention properties were studied. Water loss and unfixed water are

the leading causes of desertification, and the development of water-absorbing and water-retaining materials suitable for desertification is one of the severe challenges facing scientists.

The Effects of Hydrogels on Microbial and Fungal Growth

Microorganisms in the soil matrix play a critical part in the nutrient pathway that plants use to obtain nutrients from the soil. The complex nutrients found in soil are broken down by a wide variety of bacteria and other single and multicellular species, which then release the nutrients to the roots of the plants in their immediate proximity. To maximize the overall output of the plant, a healthy population of nitrogen and other nutrient-fixing bacteria must be maintained, as demonstrated by Jacoby et al. (2017).

(Chiara Turioni et al., 2021) published an article titled "Biodegradable Hydrogels: Evaluation of Degradation as a Function of Synthesis Parameters and Environmental Conditions". In the last century, the worldwide population has increased dramatically, with a consequent increase in food and primary resource demand. In an attempt to satisfy this growing need, uncontrolled exploitation of the farmlands began, which led to the development of more productive and less sustainable agricultural systems.

Hydrogel Impact on Plant Growth

It is essential to examine the effect of the altered soil water interactions due to hydrogel's application on the plant's growth. A large number of studies have been carried out in this regard in Agronomy. The hydrogel is applied to the plants by different methods: either seedlings or seeds are coated with hydrogel, or hydrogel is mixed with the soil adjacent to the sown plants (Kazanskii & Dubrovskii (1992)).

(Elena Khan et al., 2021) published an article titled, "Renewable Mixed Hydrogels Based on Polysaccharide and Protein for Release of Agrochemicals and Soil Conditioning". There are several issues with the significant amount of fertilizer and water lost by volatilization and leaching in large-scale agriculture. In addition, such losses hurt the final cost of agricultural products and contribute to long-term environmental pollution. Agriculture research priorities include finding innovative technologies and approaches to manage water usage better and enhance fertilizer efficiency. (Hazem S. Elshafie and Ippolito Camele, 2021) discussed about

the seed-coating technology for establishing crops a common practice to improve seed protection and enhance plant growth. Coating materials include absorbent polymers and hydrogels based on growth regulators, pesticides, fertilizers, and microorganisms.

3. RESEARCH CHALLENGES, GAPS AND LIMITATIONS

Research Challenges and Gaps:

1. *Soil Characteristics with paddy yield efficiency:*

Many subtype soils are present in major soils which influence the water requirement and are difficult to assess.

2. *Climatic Variation study along with moisture content in air in paddy cultivation:*

Kharif and Rabi seasons along with daily variation in climate also affects the growth and requires enough data to analyze.

3. *Hydrogel mixed polymer efficiency study mixed with water requirement:*

Implementation of this polymer is not extensively done in Indian conditions and contextual water table data is required.

4. *Degradation of Hydrogel after mixing with the Soil:*

Degradation studies with improvised data collection can be very helpful to conclude whether monomers are formed if hydrogel is exposed to higher temperatures

The major limitations that need to be overcome are:

1) Drawing of water retention curve for the soil-hydrogel-water matrix along with soil water potential experiments.
2) Study of slow-release kinetics of hydrogel in relation to different environmental exposure was limited to exposure to just the open atmosphere.
3) The plant growth study was conducted under open environmental conditions with less protection from insects, and fauna.
4) Only one commercially available hydrogel product was studied and was limited to time constraints. A comparative study can be done to assess market reality in the Indian scenario.

4. PROBLEM IDENTIFICTION & STATEMENT

Being the most grown crop in India and the most consumed food in southern states, Rice requires a large amount of water for cultivation and its yield is getting rapidly affected with climatic variations especially in drought scenarios. The existing research gap on knowledge about how to reduce the Paddy water consumption without compromising on crop yield could be a research problem worth pursuing. Hydrogel application in paddy cultivation could be a means for optimization of soil water retention and crop yield. The following questions could be explored to address the research gap:

- ✓ *What is the net decrease in water intake and increase in the net yield when hydrogel is applied compared to the traditional methods in paddy cultivation?*
- ✓ *What is the influence of net variation of yield based on seed types (BPT 5204 {Sona Masoori} & NDLR7 {Nandyal Sona})?*
- ✓ *How the improvements can be brought in while implementing hydrogel polymer in response to climatic variations?*
- ✓ *What is the level of biodegradation when a hydrogel is exposed to extreme temperatures?*

5. OBJECTIVES

Considering the above facts in view, the research plan proposal entitled "Soil Moisture Retention and Yield Optimization in Paddy Crop Through Hydrogel Application" was devised with the following objectives:

1. Evaluate water retention in soil and crop yield when hydrogel is applied in paddy field.
2. Analyze the changes in Soil characteristic due to the application of hydrogel.
3. Verify hydrogel degradation due to environmental exposure at the field.

6. TOOLS AND METHODOLOGIES

The Randomized data control trial (RCT) method is a trial in which subjects are randomly assigned to one of two groups: one (the experimental group) receiving the intervention that is being tested, and the other (the comparison group or control) receiving an alternative (conventional) treatment. The two groups are then followed up to see if there are any differences between them in outcome. The results and subsequent analysis of the trial are used

to assess the effectiveness of the intervention, which is the extent to which a treatment, procedure, or service does the samples better than harm. RCTs are the most stringent way of determining whether a cause-effect relation exists between the intervention and the outcome. For this study, seeds from two rice varieties were selected, namely BPT5204 and NDLR07, for the study to be conducted.

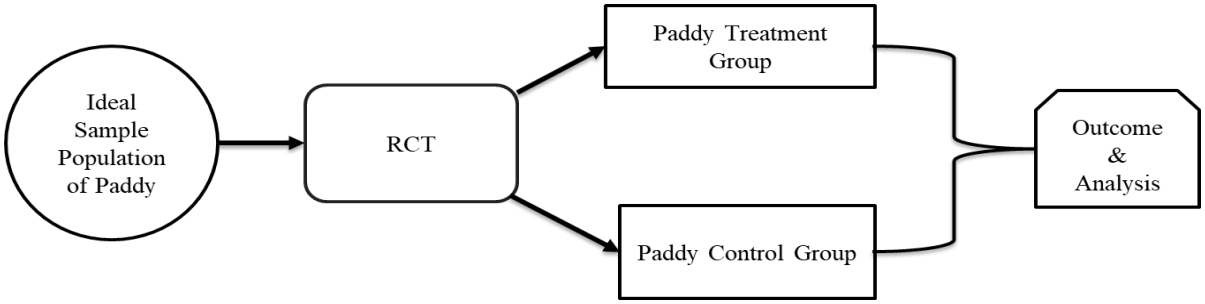


Fig 1: Randomised Control Technique (RCT) methodology

BPT5204 has been used in the local area to cultivate rice, whereas NDLR07 is a recently developed, drought-resistant variety (Jayalakshmi et al., 2020). Compared with BPT5204, NDLR07 shows a more significant economic benefit and a better yield. The study on seed growth as influenced by hydrogels would provide a better understanding of the role of climatic change in agricultural practices.

The experiment and result analysis were conducted at Krishi Vigyan Kendra (an integrated part of the National Agricultural Research System in India), Banganapalle, Andhra Pradesh (Figure 1); the site of the experimental station. The experiments were conducted during the rabi season from February 2021 to June 2021 under sandy loam soil (75 % sand, 12 % silt, and 13 % clay). The randomised controlled trial design consisted of a Control and Treatment group, as shown in Figure 2. The total net plot area of the experimental setup is 576 square meters. The treatment groups were grown in soil amended with hydrogel and three different levels of water deficits, based on a previous study (Prakash et al., 2021).

The control group was supplied with 1 cm of water for 28 days after sowing (DAS), 2.2 cm of water from 28-45 DAS, and 0.5 cm of water till the maturation crop was ready for harvest. In order to meet the deficit conditions, the treatment groups were provided at various intervals.

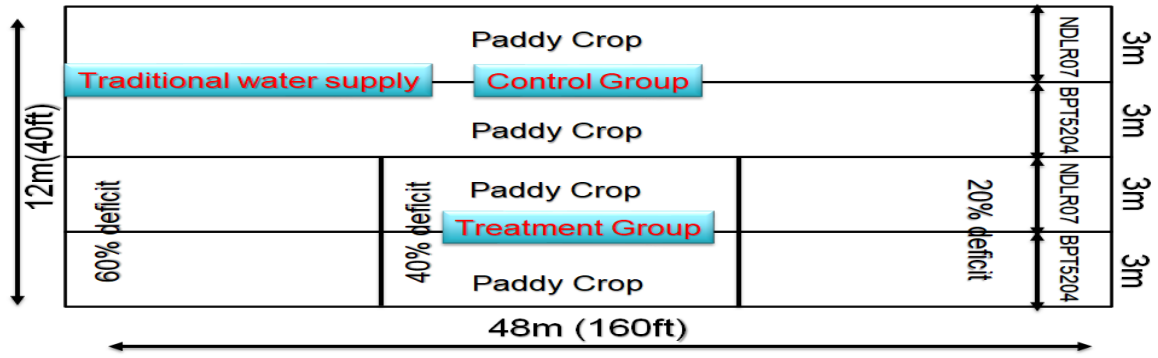


Fig 2: Layout of experimental groups for comparative study in the field for NDLR07 and BPT5204.

After two weeks of withholding irrigation in the absence of rain, in order to induce a drought condition, the tolerance of crops to water stress was observed and compared with its correlation with the application of hydrogel. The drought conditions were created between the 100th and 114th day after sowing (Days after sowing). The harvest was carried out manually during the second week of June 2021, when the panicles were fully ripened.

The hydrogel was applied manually at the time of soil preparation at 2.5 kg/ha as per ICAR recommendations (Lather et al., 2015; Kalhapure et al., 2016). Sprouted paddy seeds were sown using the drum seeder. A fertilizer dose of 133–85–62 kg NPK/ha was applied. Weed Management was done through a Cono weeder (Sudharani et al., 2019), and it was run in the direction in which the drum seeder was pulled. All other agronomic practices were kept regular and uniform for all the treatments. The treatment group received a 40% deficit supply of all the supplies to the crop compared to the control group.

7. ACCOMPLISHED RESEARCH WORK

In the experiments, the effect of hydrogel on growth parameters such as plant height, the number of tillers, dry matter production, relative growth rate, crop growth rate, and leaf area index were clearly observed. The experimental designs for the first stage were primarily adopted from studies done by [Zhang et al., 2014], [Montesano et al., 2015], [Cannazza et al., 2014], and [Chandana]. They first investigated the water absorbency of the superabsorbent polymer under consideration and verified their effects on crop growth comparatively. After ascertaining the first stage of this study, the applicability in field level was evaluated by adopting the right study site and crop variety

For the NDLR 07 variety of paddy, mixed with Hydrogel and 20% less water supply, better results were produced, as evidenced by the higher plant heights. For BPT5204 and NDLR07,

the hydrogel-water combination used in the hydrogel treatment used 40% less water than the control group showed maximum tolerance to drought and significantly higher grain weights and panicles. Fig 3 determines the plant height and BPT40 and NDL20 are leading the graphical representation.

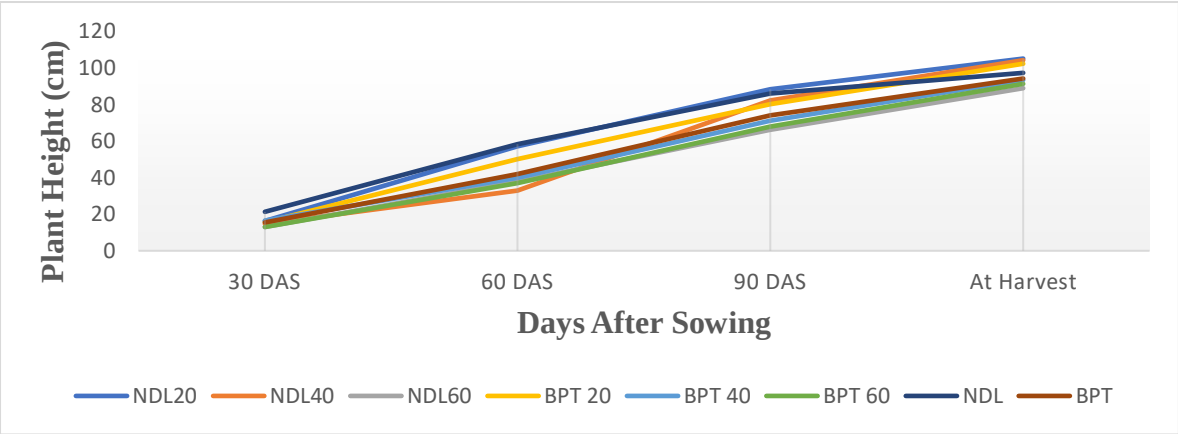


Fig 3: Effect of seed varieties and hydrogel on plant height

Overall growth is the combination of all the growth supporting parameters like tillers, panicle length, plant height and 1000 grain weight through which the assessment is done. Best result of growth parameters was found with application of hydrogel at NDL 20 and BPT 40 treatment groups.

The area per plant of each leaf was computed using a leaf area meter. Readings were taken at 30, 60, and 90 days after sowing (Fig 4). It was impossible to measure it at harvest because the leaves had completely dried out. The leaf area index was calculated by dividing the leaf area per unit land area, given by Sestak et al. (1971). LAI = Leaf area / Land area

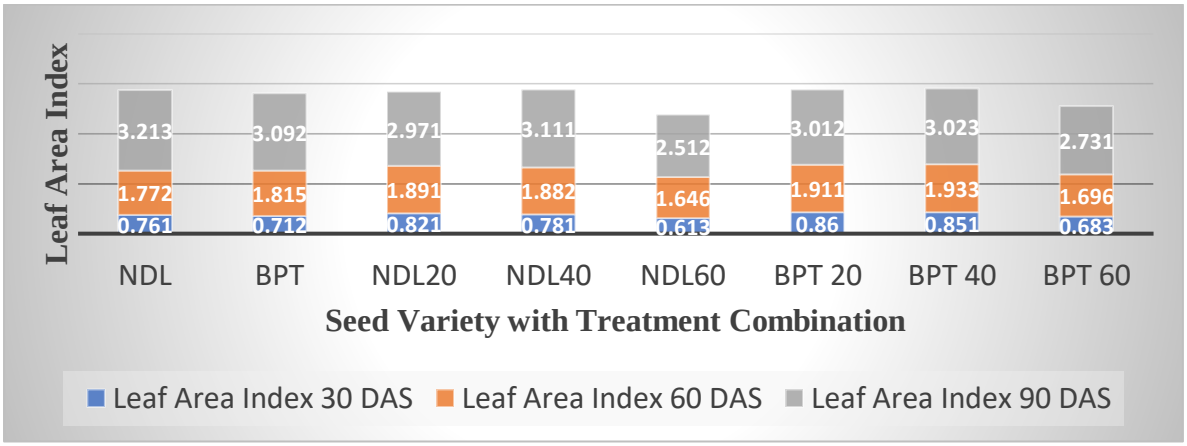


Fig 4: Effect of seed varieties and hydrogel on Leaf Area Index

After drought induction crop of BPT5204 shows maximum tolerance to water stress condition and survive more but it was at par with NDLR 07 variety. This combination of Hydrogel and 20% less water supply for the BPT 5204 variety of Paddy yielded better results and was evident in the height of the plants. By combining the BPT 5204 and NDLR07 drills with 20% less water supply, this resulted in a higher number of tillers being produced. It is the rate of the dry matter production rate per unit ground area per unit time, and it was computed by using the formula suggested by Watson (1952). It was expressed in g dm-^{2}day-^{1}.

CGR = W2 – W1 / 1 t2 – t x 1 / A

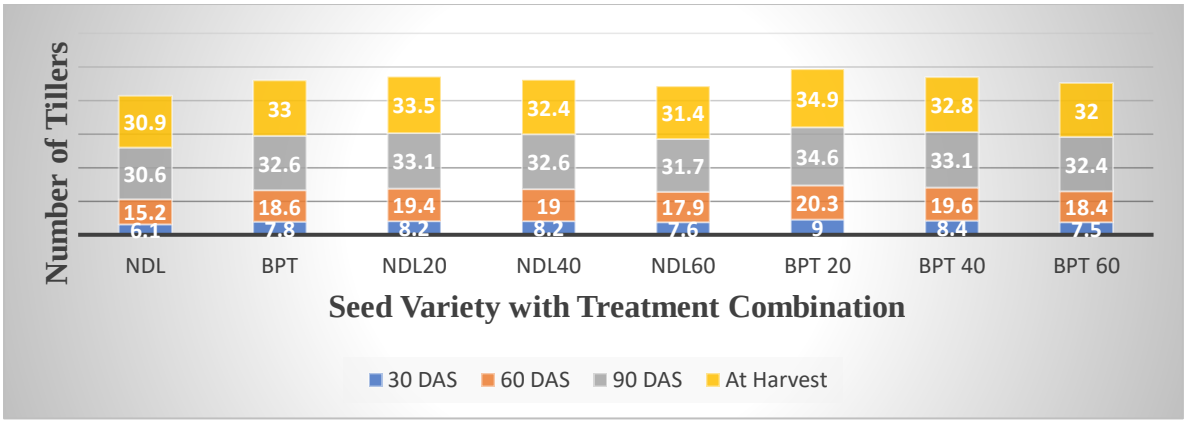


Fig 5: Effect of seed varieties and hydrogel on number of tillers

Whereas to calculate relative growth rates for different periods, Hoffmann and Poorter (2002) proposed the following formula for estimating relative growth rates (g/g/day).

RGR = logW2 – logW1 / t2 – t1

The impact of weather conditions on crop growth, development, and overall performance during the crop season is one of the most important factors determining the extent to which crops grow, develop, and perform overall. From each plot, 10 panicles are selected randomly, the panicle length (Fig 6) is measured from the base to the tip of the panicle, and the average length of the panicle is calculated.

In the case of rice, meteorological conditions are particularly important because it requires high temperatures, humidity, and precipitation during the vegetative phase, as well as longer periods of sunlight during the reproductive phase, in order to produce a higher yield of grain. Crop development and output can be negatively affected by even a little divergence from the normal

range of environmental circumstances. Grain samples were obtained from each plot's cleaned produce, and 1000- grains were counted and weighed (Fig 7).

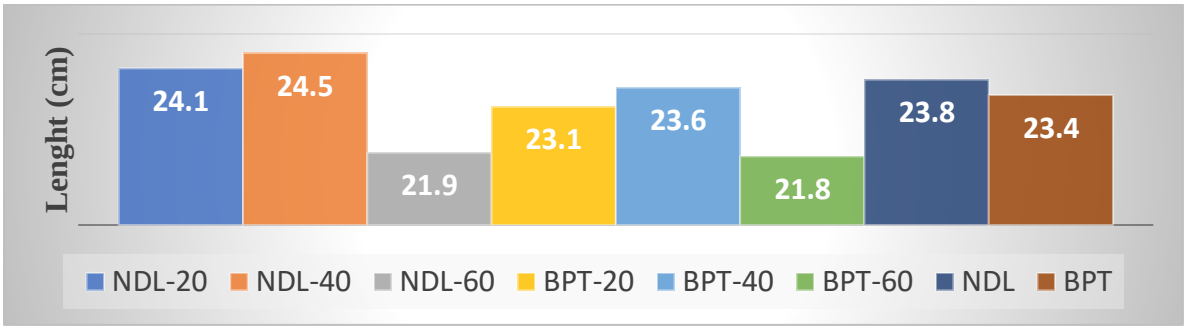


Fig 6: Effect of seed varieties and hydrogel on panicle length

The temperature will likely vary very much for a year, and the temperature can vary considerably from one place to another (Fig. 8). During November and December, the weather is fine with few raindrops, and the wind is light with a lot of dew. The year's average rainfall for the district is 920 millimeters. The average rainfall for 2021-22 recorded was 572.19 millimeters.

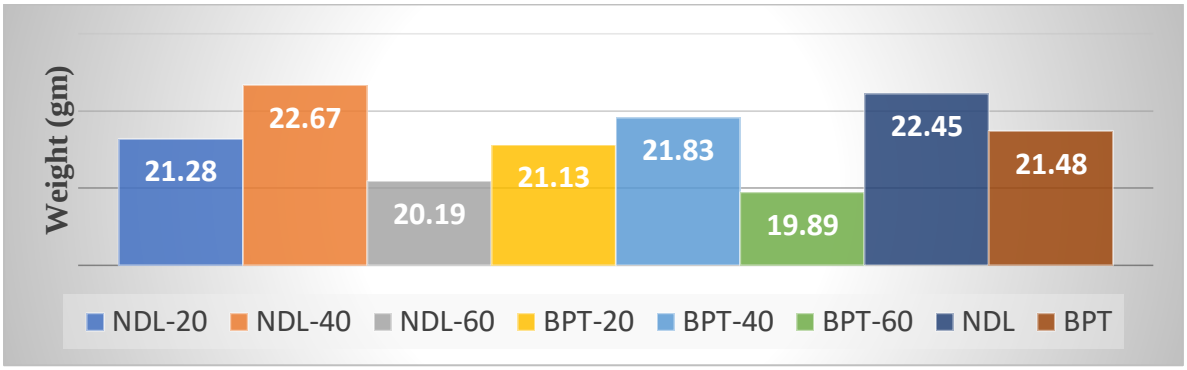


Fig 7: Effect of seed varieties and hydrogel on 1000 grain weight.

8. RESULTS AND DISCUSSIONS

The meteorological data (Fig 8) and regular field observations demonstrate that the crop was nearly completely unaffected by weather changes, with the exception of a few brief bouts of short-term drought during the later stages of the crop during 100 to 114 DAS. Irrigation was provided whenever moisture stress developed in field plots in order to keep the moisture stress under control. Immediately upon the induction of the drought, all external water sources were stopped from maintaining the water-stressed state.

From the seed treatment, the chosen seeds were sunflower and paddy. The optimum dosage was found to be 0.75 %. The plant growth analysis was done for two soil types, namely red and black soil. The method of irrigation used was a surface drip irrigation system. The schematic diagram (Fig. 9) below shows the arrangement and placement of the plant species with the drip irrigation system.

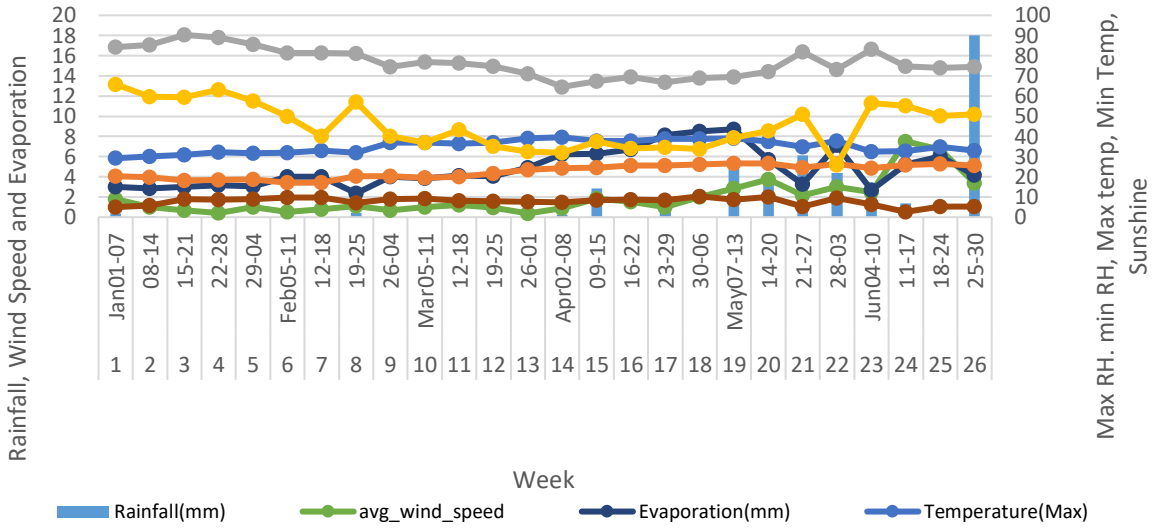


Fig 8: Mean standard week-wise meteorological parameters during crop season

The drip irrigation system was controlled via valves and connectors. The discharges were kept at minimum and the watering schedule was adjusted to provide 100% of the water requirement to the control groups, 20% deficit for one group with application of hydrogel, and 40% deficit for one other group with hydrogel, for each crop. The 20th day plant growth was measured to assess the effects of hydrogel. The plant height was measured from the base of the stem at the level of soil to the tip of the longest leaf.

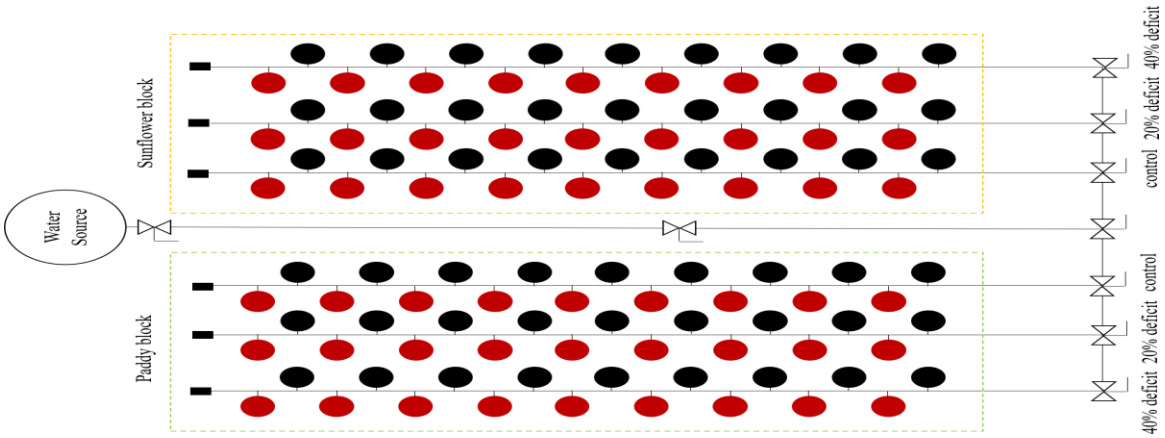


Fig 9: *Diagrammatic plan of plant growth study drip irrigation setup.*

It is possible that adequate fertilizer availability and satisfactory moisture conditions sustained throughout the growing season contributed to an increase in the soil's capacity to deliver nutrients during the growing season. Having a good start and improving growth indicates that the crop is using the nutrients available to it in the best possible way.

Additionally, phosphorus is found in significant quantities in ATP, the chemical that gives the plant energy to carry out these processes and others. Higher dissolved oxygen levels in the root zone of most crops results in a higher root mass. A plant with more root mass grows healthier and faster. Chloride is not adsorbed or held back by soils; therefore, it moves readily with the soil-water, is taken up by the crop, moves in the transpiration stream, and accumulates in the leaves. If Water with high TDS is applied to your soil, the root systems of the plants will eventually have trouble taking up many of the nutrients you have applied.

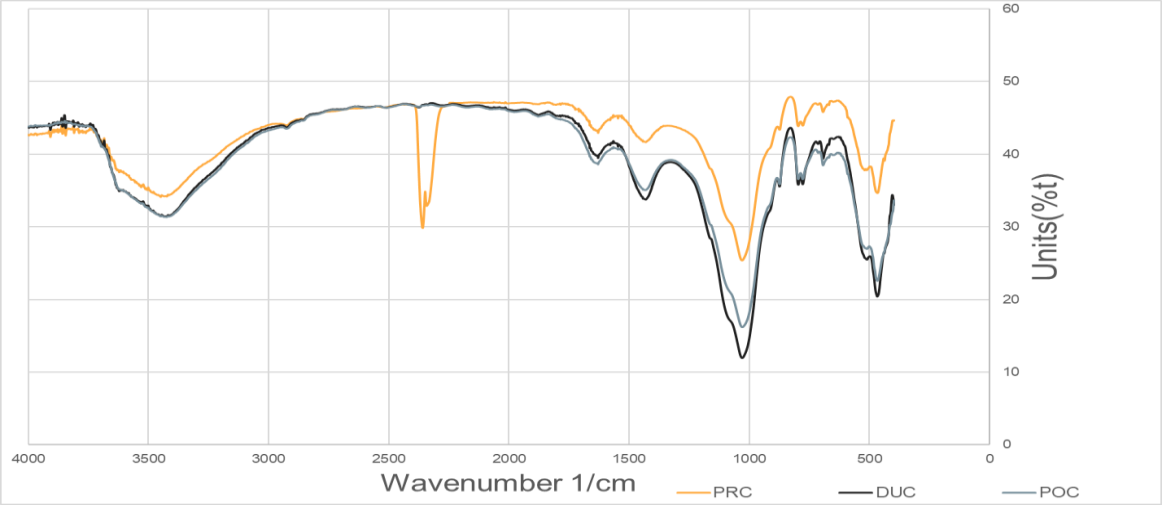


Fig 10: Cumulative FTIR Peaks of Various crop stages

Three Stages of Bio Degradation was Taken for Evaluation in both FTIR & SEM

1)Pre-Crop 2) During Crop 3) Post Crop

Peak Intensity was found during the first stage of Evaluation, in which most of the Peaks were found to be present in the different regions (Fig 10) of the Wave Numbers. During the second and third stages, most of the Peaks were missing due to the microbial breakdown of the samples and the change in the functional groups of those particular elements present in the samples.

Temperatures were as high as 40 Degree Celsius, and hydrogel exposed to UV index is also considerably high. The morphological alterations of the synthetic hydrogel that was employed were discovered using SEM examinations. The findings of the pre-Crop SEM hydrogel analysis revealed cross-linking and the absence of cracks (Fig 11). The SEM photos of the remaining biodegradation phases revealed clear evidence of hydrogel degradation in the soil at various time intervals, which was confirmed by the results of the experiment.

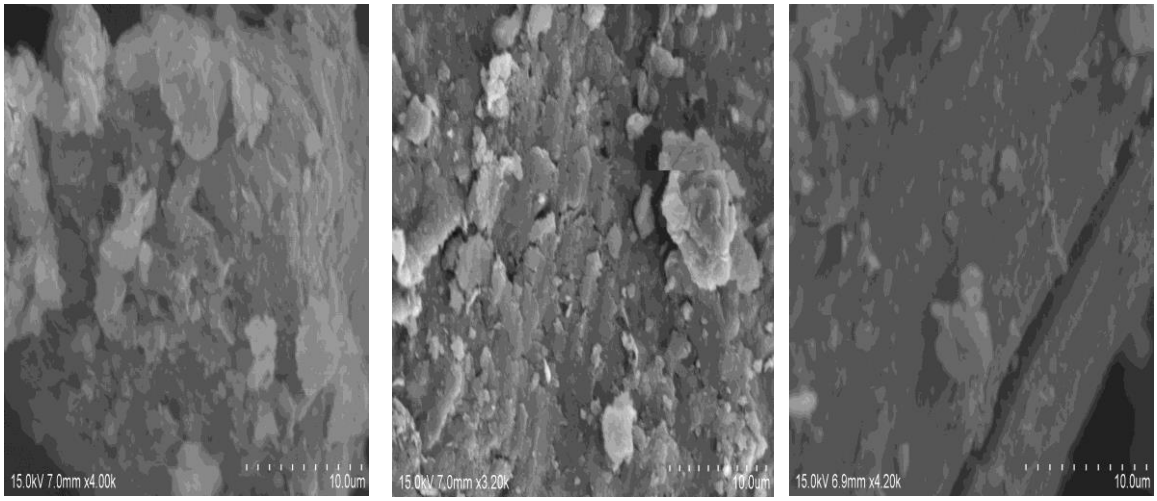


Fig 11: Morphological changes of Soil in various Crop stages of Paddy

When the biodegradation process reached the post-Crop stage, the fissures appeared on the surface (Fig 11). When the biodegradation period was prolonged, the intensity of morphological damage increased as well. Biodegradation was found in large, voluminous fractures as well as shallow pits, and SEM pictures demonstrated that hydrogel is biodegradable in nature. Use of Hydrogel increased N, P, K, Organic Carbon, Iron and Manganese in the soil. Nitrogen is a constituent of protein and chlorophyll molecule. Nitrogen favours greater absorption of nutrients resulting in rapid expansion of foliage, better accumulation of photosynthates and eventually resulting in increased leaf area index and crop growth rate. Phosphorus is important for plant growth and promotes root development, tillering, and early flowering and performs other functions. Potassium helps in greater cell division, elongation and expansion resulting a proper enzymatic activity under adequate potassium concentration in plant.

Best result of growth parameters was found with application of hydrogel at NDL 20 and BPT 40 treatment groups. (Efficiency of hydrogel would vary with seed varieties). Paddy yield is the combination of yield components i.e., plant height, Tillers, 1000 grain weight, leaf area index and Panicle length. It is well documented that the addition of gel-polymers has the potential to improve plant vegetative growth by retaining more moisture contents (Choudhary et al. 1995, Al-Harbi et al. 1999). Johnson (1984) and Huttermann et al. (1999) reported that the addition of gel-polymer to sandy soil could change the water-holding capacity.

Yezdani et al. (2007) reported more yield of soybean by hydrogel application in drought-prone regions. The present study also shows high yield in the rice varieties grown in similar eco-zone. Bhardwaj et al. (2007) used water absorbents in sandy soils from arid and semiarid regions and

reported hydrogel as an important catalyst in increasing water use efficiency and crop production. Present investigations reinforce the same. The results of present study match with the findings of Hayat and Ali (2004); Madiwalar and Prabhakar (1998) who stated that absorption of water by synthetic polymer and its effect on yield parameters helps to increase the yield of crops. The hydrogel molecules are too voluminous to be absorbed into plant tissue and have zero bioaccumulation potential and is not sensitive to the action of UV and not degraded into Oligomers as suspected by Neethu (2018)

Higher 1000g weight was observed in the present study. Khadem et al. (2010) also showed that the adding superabsorbent polymer can linearly increase 1000-grain weight of field crop. Similar result was also found by several researchers (Kimura et al. (1992) in his experiment found similar type of higher field emergence in field conditions using different cultivars of cotton. Similarly, results of Harman et al. (2004); Lo et al. (2002); Chien Yih Lin et al. (2002); Akhtar et al. (2008) and Hassan et al. (2013) had similar findings. Nitrogen, phosphorus and potassium content in the soil under treatment having application of hydrogel increased substantially (Singh e*t al. (*2017) reported that hydrogel application increased nutrient contents particularly N, P and K by prevention from leaching losses. Similar results were also found by Dordas *et al. (*2008), Azarmi *et al. (*2011) and Li e*t al.* (2015)). Decreased water consumption and increased water-use efficiency could provide a unique mechanism for symbiotically conferred drought tolerance (Chepsergon *et al.*, 2012).

The SEM results have shown that after 60 DAS, there was significant fragmentation of the soil surfaces with rough morphologies, indicating that the degradation surface of the cross-linked hydrogels. Saruchi Sharma (2014) and others synthesized some polysaccharide hydrogels, such as baicalin/polyacrylic acid/copolymerized methacrylic acid hydrogels most of which degraded in the major portions. But the present study indicates, the slow decomposition of synthetic hydrogels could prolong to multiple crop cycles in a farm. Burkhard et al. (2014) found that the average degradation started from 10 DAS of polyacrylate hydrogel and maintain consistency after 90 DAS. Because of this degradation consistency retention time decreases.

9. CONCLUSION

Agriculture's long-term viability is critical to improving food and water security, particularly in the face of climate change. Within the last few years, the application of hydrogels in

agriculture has attracted a great deal of attention from both researchers and farmers alike. Water intake is an essential component of any crop's function. A favorable soil environment with high moisture content is required immediately after seeding to ensure successful germination of the seedlings in the soil. Viable soil conditions were accomplished through hydrogel with a deficit in water intake through optimization. Higher germination rates and more rapid and healthy growth of the plant were achieved by increasing the amount of water available to the seed during critical periods of its growth. The addition of hydrogel had a favorable effect on the plant, which grew at a faster rate as a result of the addition.

The maximum plant growth was observed in paddy fields with a 20 and 40 percent shortfall in water. The enhanced plant growth with decreased water input is an intriguing discovery that should be further investigated, according to the researchers. When it comes to dry and semi-arid locations, the hydrogel has the potential to be an excellent soil conditioner. It would improve the texture of the soil, offer the necessary porosity for optimal air and water flow, decrease the effect of soil salt on plants, and release stored water in the soil that has dried out. When used as soil conditioners, hydrogels can help to enhance water usage efficiency as well as plant health and productivity. Soil water retention has also improved while also lowering irrigation water requirements. So, hydrogel application would be advantageous for paddy and wheat crops, which have huge water footprints, to name a few examples.

The hydrogel has the potential to improve the root-soil-water connection in crop systems, hence promoting crop growth. The use of NDLR07 as a drought-resistant crop that has been supplemented with hydrogel would help to prevent damage and loss as a result of drought. When supplemented with hydrogel, the BPT5204 strain has shown more tolerance to drought conditions. The rise in productivity achieved through soil conditioners such as hydrogel would aid ensuring long-term viability, allowing the farmers to reap the advantages of their efforts.

BIBLIOGRAPHY

[1] Chaithra, G. M., and S. Sridhara. "Yield and Physiological Parameters of Maize as Influenced by the Application of Super Absorbent Polymer and Mulching Under Rainfed Conditions." *Int. J. Curr. Microbiol. App. Sci*, 7.8 (2018): 216-224.

[2] Chaithra, G. M., and S. Sridhara. "Growth and yield of rainfed maize as influenced by the application of super absorbent polymer and Pongamia leaf mulching." *IJCS* 6.5 (2018): 426-430.

[3] Devineni, Naresh, Shama Perveen, and Upmanu Lall. "Assessing chronic and climate-induced water risk through spatially distributed cumulative deficit measures: A new picture of water sustainability in India." *Water Resources Research* 49.4 (2013): 2135-2145.

[4] Jacoby, Richard, et al. "The role of soil microorganisms in plant mineral nutrition—current knowledge and future directions." *Frontiers in plant science* 8 (2017): 1617.

[5] Lamochi, Sadegh, and Tayeb Sakinejad. "Assessment effect of super absorbent polymer and Nitroxin on growth curves and corn (Zea mays L.) production." *Journal of Crop Nutrition Science* 4.4 (2018): 33-46.

[6] Nassiri-Mahallati, Mahdi, and Mohsen Jahan. "Using the AquaCrop model to simulate sesame performance in response to superabsorbent polymer and humic acid application under limited irrigation conditions." *International Journal of Biometeorology* 64.12 (2020): 2105-2117.

[7] Parthasarathi, Theivasigamani, et al. "Evaluation of drip irrigation system for water productivity and yield of rice." *Agronomy Journal* 110.6 (2018): 2378-2389.

[8] Prakash. Surya, et al. "Sustainable water consumption of rice (Oryza sativa L.) as influenced by the superabsorbent polymer in water-stressed conditions." *International Journal of Modern Agriculture* 10.1 (2021): 857-866.

[9] Roy, Trisha, et al. "Impact of Pusa hydrogel application on yield and productivity of rainfed wheat in North West Himalayan region." *Current Science (00113891)* 116.7 (2019).

[10] Parthasarathi, Theivasigamani, et al. "Evaluation of drip irrigation system for water productivity and yield of rice." *Agronomy Journal* 110.6 (2018): 2378-2389.

[11] Youssef, Sabry, et al. "Amending sandy soil with biochar or/and superabsorbent polymer mitigates the adverse effects of drought stress on green pea." *Egyptian Journal of Horticulture* 45.1 (2018): 169-183.

[12] Khan, Elena, et al. "Renewable mixed hydrogels based on polysaccharide and protein for release of agrochemicals and soil conditioning." Sustainability 13.18 (2021): 10439.

[13] Elshafie, Hazem S., and Ippolito Camele. "Applications of absorbent polymers for sustainable plant protection and crop Yield." *Sustainability* 13.6 (2021): 3253.

[14] Rodrigues Sousa, Heldeney, et al. "Superabsorbent hydrogels based to polyacrylamide/cashew tree gum for the controlled release of water and plant nutrients." Molecules 26.9 (2021): 2680.

[15] Turioni, Chiara, et al. "Biodegradable Hydrogels: Evaluation of Degradation as a Function of Synthesis Parameters and Environmental Conditions." *Soil Systems* 5.3 (2021): 47.

PUBLICATIONS & PROCEEDINGS

I. Papers in Journals

[1]. S. Prakash, S. Vasudevan, A. Banerjee, A.C. Joe, K.N. Geetha, and S.K. Mani, "Sustainable irrigation through Application of Hydrogel: A Review," *Alinteri J. of Agr. Sci*., vol. 36, no. 2, pp. 38–52, Jul. 2021.

[2]. S. Prakash, S. Vasudevan, A. Banerjee, A.C. Joe, G. Reddy, K.N. Geetha, and S.K. Mani, "Sustainable water consumption of rice (Oryza sativa L.) as influenced by superabsorbent polymer in water stressed conditions," *Int. J. Mod. Agr*. vol. 10, no. 1, pp. 857–866, 2021.

[3]. B.S.P. Reddy, S. Vasudevan, S.K. Mani, S. Uppaluri, and M. Sudakar, "Drought mitigation through hydrogel application in rice (Oryza sativa L.) cultivation*," J. Exp. Biol. Agr. Sci.* vol. 9, no. 6, pp. 727–733, 2021,

II. Conference Proceedings

[1]. B.S.P. Reddy, S. Vasudevan, S.K. Mani, and S. Uppaluri, "Hydrogel application in paddy cultivation to mitigate drought impact in semi-arid regions of India," presented at the *2nd Int. Symp. Disaster Resil. Sustain. Dev*., Thailand, June 24–25, 2021, DRSD21_174.

CENTRE FOR RESEARCH
DEANERY: SCHOOL OF ENGINEERING AND TECHNOLOGY
PROGRAMME: Ph.D.

VERIFICATION OF PUBLICATIONS
(ELIGIBILITY FOR PRE-SYNOPSIS/SYNOPSIS SUBMISSION)
(please fill whichever is applicable)

Name of Scholar	BOREDDY SURYA PRAKASH REDDY	Reg. No	1870071	Batch	DEC-2018	Dept.	CIVIL
Research Area	Environmental Engineering						
Research Title	SOIL MOISTURE RETENTION AND YIELD OPTIMIZATION IN PADDY CROP THROUGH HYDROGEL APPLICATION						
Provide Name, Address & Contact Details:- H.no :2-115, Peddakottala, Nandyal, Kurnool. A.P. 518502 Mobile : 9951393333							
Supervisor Dr SHIBU K MANI	Co-Supervisor NIL	External Supervisor NIL	RAC Members Dr Aravind H B Dr Sujatha Unnikrishnan				

Date of Joining Ph.D. programme	17th December 2018
Date of Proposal Defense Presentation	23rd July 2019
Date of Course Work Completion Certificate issued	19th December 2019
Date of Pre-Synopsis Presentation	4th March 2022

Bi- Annual/Annual Presentations Completed (DD/MM/YYYY)	1st Year	2nd Year	3rd Year	4th Year	5th Year	6th Year	7th Year	8th Year
	10-01-2020	12-10-2020	14-01-2021	24-07-2021	18-01-2022	-	-	-

Whether published in minimum two reputed Scopus Indexed journals as per University eligibility requirements?	**Scopus - 1**
Any other reputed indexing WoS, SCIE, UGC or listed in IEEEXplore	**WoS - 2**

No. of Publications:- 3

National Conference	**NIL**	International Conference	**1**	National Journals	**NIL**	International Journals	**3**

No. of Patents filed:- NIL

National	**NIL**	International	**NIL**

Scholar's Scopus ID	https://orcid.org/0000-0001-9893-2153
Whether your Supervisor's name is included as co-author in all your publications?	YES
Whether CHRIST University affiliation used in all publications?	YES

Justification of contributions by authors other than Scholar-Supervisor/Co-Supervisor, if included in any publications:

1) **M Sudhakar: Scientist at KVK Research Center (Field level data collection support and analysis support).**
2) **K.N.Geetha : Senior Professor at GKVK Bangalore (Lab setting support, data analysis support and manuscript review).**
3) **Sirisha Uppaluri : Assoc.Professor at Christ University (Support for conceptualizing the experiments and direction for spatial data inclusion).**
4) **Sriram : B.Tech Scholar at Christ University (support conducting the lab experiments and data analysis).**
5) **Girinath Reddy: Scholar at Jamsetji Tata School of Disaster studies (Material selection support and review)**

DETAILS

I. JOURNAL PUBLICATION

S. No.	Authors & Affiliation	Title of Paper	Journal Name	Vol/No/pp/ Month /Year	Online Link / DOI	Indexing (Scopus / SCIE / WoS/ UGC)	Quartile No.
1	Boreddy Surya Prakash Reddy, Sriram Vasudevan, Shibu K Mani, Sirisha Uppaluri, M Sudakar	DROUGHT MITIGATION THROUGH HYDROGEL APPLICATION IN RICE (Oryza sativaL.) CULTIVATION	Journal of Experimental Biology and Agricultural Sciences	Volume –9(6) page 727–733 December - 2021	http://dx.doi.org/10.18006/2021.9(6).727.733	Scopus	4
2	Surya Prakash, Sriram Vasudevan, Ankush Banerjee, Aditya C Joe, K.N. Geetha, Shibu K Mani	Sustainable Irrigation through Application of Hydrogel: A Review	Alinteri Journal of Agriculture Science	Volume 36, Issue 2, Pages: 38-52 2021-July	http://dx.doi.org/10.47059/alinteri/v36i2/ajas21113	WoS	Nil
3	Surya Prakash, Sriram Vasudevan, Ankush Banerjee, Aditya C. Joe, Girinath Reddy, Geetha K. N., Shibu K. Mani	Sustainable water consumption of rice (Oryza sativa L.) as influenced by superabsorbent polymer in water stressed conditions	International Journal of Modern Agriculture	Volume 10, Issue 1, Pages: 857 – 866, 2021 - February	http://www.modern-journals.com/index.php/ijma/article/view/678	WoS	Nil

II. CONFERENCE PUBLICATION

S. No.	Authors & Affiliation	Title of Paper	Name of Conference Organizer, and Location	Proceedings/Book Chapter / Special Issue	Online Link /DOI	Indexing (Scopus / SCIE / WoS/ UGC)	Quartile No.
1	Boreddy Surya Prakash Reddy, Sriram Vasudevan, Shibu K Mani, Sirisha Uppaluri, M Sudakar	Hydrogel application in Paddy Cultivation to Mitigate Drought Impact in Semi-Arid regions of India	2nd International Symposium on Disaster Resilience & Sustainable Development	Proceedings	https://online.pubhtml5.com/tqto/sqru/#p=230	Scopus	NA

III. PATENT DETAILS

S. No.	Name of Inventor & Affiliation	Application / Patent No.	Type of patent & Country (Indian / International)	Status (applied/ published/granted)	Link for verification
	Nil	Nil	Nil	Nil	Nil

IV. CONFIRMATION

1. All the above details have been filled in concurrence with my research Supervisor.
2. The copies of published versions of papers/patent filed documents will be added in the pre-synopsis/synopsis report.
3. Proof of document for all necessary items mentioned above will be made available for verification any time.
4. I understand the requirements to be fulfilled for the submission of Pre-synopsis/Synopsis.
5. I shall abide by the procedure of the Centre for Research of our University and submit well before the timeline given.
6. The details and information provided above are correct to the best of my knowledge.

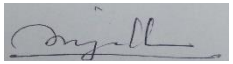
V. PhD Degree nomenclature recommended by the Supervisor (based on the area of research):

Discipline: Civil Engineering

Remarks by Supervisor:

Mr Boreddy Surya Prakash Reddy has accomplished all the objectives of his research work considering the suggestions of the RAC members from time to time. He has published one paper in a Scopus indexed journal and two papers in web of science indexed journals. He has participated and presented a paper in an international conference. Considering the accomplishments of the scholar, I recommend him for synopsis presentation

Signature

Submitted by	Recommended by	Verified by	Forwarded by
			
Boreddy Surya Prakash Reddy	**Dr SHIBU K MANI**	**Dr Sujatha Unnikrishnan**	**Dr Raghunandan Kumar**
Scholar	Supervisor	Dept. PhD Coordinator	HoD

Date: 18th March 2022

(CFR-KC Office Use Only)

This

Certificate of Participation

is awarded to

Mr. Boreddy Surya Prakash Reddy

for participating in the

2ND INTERNATIONAL SYMPOSIUM ON DISASTER RESILIENCE & SUSTAINABLE DEVELOPMENT

held virtually on 24-25 June 2021

Indrajit Pal

Dr. Indrajit Pal
Chair
Organising Committee, *DRSD 2021*
Disaster Preparedness, Mitigation, and Management, *AIT, Thailand*

International Journal of Modern Agriculture, Volume 10, No.1, 2021
ISSN: 2305-7246

Sustainable water consumption of rice (Oryza sativa L.) as influenced by superabsorbent polymer in water stressed conditions

Surya Prakash[1], Sriram Vasudevan[1], Ankush Banerjee[1], Aditya C Joe[1], Girinath Reddy[2], Geetha K N[3], Shibu K Mani* [1]

1. CHRIST (deemed to be university), School of Engineering and Technology, Department of Civil Engineering, Bengaluru, Karnataka, India

2. Jamsetji Tata School of Disaster studies, Tata Institute of Social Sciences, Mumbai

3. Department of Agronomy, University of Agricultural sciences, GKVK, Bengaluru, Karnataka, India

Abstract

Sustainability in irrigation and agriculture has received widespread attention among researchers across the globe in the recent decade. To ensure food security and to protect water resources, agricultural and irrigation practices need to be amended with innovative technology that conserves water and increases productivity. The application of SAP or hydrogel as soil conditioners was identified as a possible solution to increase water use efficiency in irrigation. This study aimed to evaluate the swelling properties of hydrogel and its effects of hydrogel application to the soil on plant. Paddy was chosen for plant growth assessment due to its large water footprint. Laboratory scale experiments were carried out in growth bags for control group (TC1) supplied with excess water and treatment groups (20% - TC2, 40% - TC3, and 60% - TC4 deficit supply of water) amended with hydrogel under drip irrigation. Hydrogel exhibited an equilibrium swelling of 513.3 (TH1 - deionized water), 188.8 (TH2 - groundwater) and 121.9 (TH3 - 0.5 % saline water) times its dry weight respectively. The water retention time in hydrogel was maximum for saline water, followed by groundwater, and deionized water. Seed treatment of paddy showed the optimum dosage of hydrogel to be 1.25% by weight of seeds. The plant height at 2 weeks after sowing showed significant trend of increasing plant height in the order of TC1 (17 cm) > TC2 (23 cm) > TC3 (24 cm) > TC4 (28 cm). The results support the hypothesis that hydrogel can be advantageously used in soil conditioning as an effective way to protect irrigation water resources and to ensure food security.

Keywords: Hydrogel, Irrigation, Paddy, Water Consumption, Sustainability.

I.INTRODUCTION

Water is the most consumed resource on earth and irrigation has a major share of consumption in agriculture. Almost three-fourth of potable water is used for irrigation alone across the world (ICAR, 2019). The prevalence of water stress in arid and semi-arid regions calls for the protection of water resources. Moreover, climate change studies project uncertain and erratic rainfall and extreme weather conditions (ECOSOC, 2019; Jha et al., 2016; Piao et al., 2010) adversely affecting crop cultivation, which

in turn affects the food security (Roy et al., 2019). To protect water as a resource and to ensure food security, sustainable irrigation practices become necessary. Sustainability in irrigation can be brought by engineering the conveyance and application of water in the agricultural fields, and enhancing the water use efficiency of plants. Water influences photosynthesis, absorption, respiration and other internal processes for any crop. By increasing the root zone soil water retention, the living conditions of crops would be enhanced, and the water use efficiency effectively increases (Jacoby et al., 2017).

Establishment of a fertile land in big proportion always have had constraints such as lack of financial resources, appropriate land, fertile soils and stable water sources (Shooshtarian et al., 2012). In India, land and water availability are limiting factors for large-scale production for actual food demand. Irrigated areas account for nearly 48.8 % of the cultivated area and the remaining 51.2 % are rainfed in the country. The major problem of the rainfed cultivations is that the crop production is only about half that of the irrigated area (CWC, GoI, 2019). In densely populated arid and semi-arid regions, high water stress compels a shift towards unconventional methods to attain sustainability in agriculture, to meet required food production levels within the available water resource levels.

Paddy is a premier food crop in Asian countries. Almost 90% of the world's rice is produced and consumed in Asian countries alone, China being the primary producer, followed by India (FAO STAT, 2019-20). Requiring almost 5000 litres of water for 1 kg rice grain production using traditional methods, globally rice production consumes 40% of freshwater (Parthasarathy et al, 2018). Enhancing the irrigation efficiency for paddy would play a significant impact in protecting water resources.

The application efficiency can be enhanced by use of drip irrigation (Jha et al., 2016). Aerobic cultivation is shown to produce more yield in paddy than conventional methods (Parthasarathy et al., 2018). Further, soil conditioners are known to enhance the water use efficiency. Superabsorbent polymers are widely used soil conditioners (SAP). The term SAP is alternatively used with the term hydrogel. Hydrogel is defined as a three-dimensional polymeric network that can retain a significant amount of water within its structure and swell without dissolving in water (Jamnongkan & Kaewpirom, 2010; Guilherme et al., 2015). Figure 1 shows swollen hydrogel particles. The particles when in soil, act as water reservoirs from which roots of the plants can absorb water. (Agaba et al. 2011) demonstrated an increase in water use efficiency while the roots of plants formed a complex with soil and hydrogel. Similar studies on paddy are necessary to assess and contribute to sustainability. To that end, the effect of hydrogel on the water use of paddy is the object of study in this paper.

Figure 1: Swollen hydrogel particles in 200 ml beaker.

The scope of the present study includes experiments on swelling properties of hydrogel and small-scale comparative investigation of growth of paddy in loamy soil under the influence of said soil conditioner. A randomized control method was adopted to account for exposure to wind, sunlight, humidity, and temperature. The crop growth was monitored only for the first stage (tillering) due to COVID-19 restrictions. The following sections elaborate on the methods, materials, results, discussions and conclusions drawn from the study.

II. MATERIALS AND METHODS

Materials

Experimental site and soil characteristics: This study was conducted at CHRIST (deemed to be university), School of Engineering and Technology, Bengaluru. Karnataka, India during January - March, 2020. Loamy soil was used for the study. The details of the soil used are tabulated in table 1.

Hydrogel: The hydrogel used for the study was purchased from Agrionics India and the hydrogel is sold under the brand name "Magic hydrogel" (acuro), which is a slow-release potassium polyacrylate-based SAP with a swelling ratio of 500. The filter used for swelling test was "Atoz prime 1Mx1M Nylon Filtration Sheet Water oil industrial filter cloth 200 mesh". Water used for testing included deionized water, saline water (0.5% w/w NaCl), and groundwater (electrical conductivity 1346 µS/cm and pH 7.5).

Crop growth: The fertilizers used for the study were urea - 46% nitrogen, diammonium phosphate (DAP) - 46% phosphorus, and muriate of potash (MOP) - 60% potassium. Farmyard manure used was an organic nutrient rich mix obtained from composting. The paddy seeds used were of hybrid variety Ankur 13555.

Table 1: Characteristics of soil for experimental study

Characteristics	value
Texture	Loam Soil
Sand (%)	40
Silt (%)	35
Clay (%)	25
Colour	Black
Zn (zinc)	0.27(deficiency)
Fe (Iron)	8.14
Cu (copper)	5.132
B (Boron)	0.43 (deficiency)
S (sulphur)	31 (HIGH)
Ca (calcium)	0
N (Nitrogen)	268.09 kg/ha
P (Phosphorus)	27.47 kg/ha
K (Potassium)	305.98 kg/ha

Methods

Soil tests: The index properties of soil were found out using sieve analysis and pycnometer specific gravity test as per the code of Indian standards (IS 2720: 1983). The specific gravity was found out to be 2.34.

Seed Treatment: seed treatment with hydrogel was done under laboratory conditions. The method was as described in detail by (Chandana S S 2019). This test was conducted to determine the optimal dosage of the hydrogel for germination. The seeds were placed in petri dishes and different doses of hydrogel were administered (0.5 %, 0.75 %, 1 % and 1.25 % by weight of seeds). One control group was left without hydrogel. 10 ml of water was added to each dish and left in a dark chamber for 10 days for paddy seeds. The radicle length was measured for each seed and the average germination index was calculated by the equation 1 (Francesco *et al*., 2015):

$$GI = \left(\frac{G}{G_0}\right) \times \left(\frac{L}{L_0}\right) \times 100 \qquad \ldots \text{(Eq 1)}$$

Where *GI* is the germination index, *G* and *L* are the number of germinations and average radicle length respectively under hydrogel treatment; G_0 and L_0 are the number of germinations and average radicle length of control group.

Hydrogel swelling: The swelling was studied according to methods adopted in similar research studies (Cannazza et al., 2014; Guilherme et al., 2015). The swelling of hydrogel for increasing time intervals of immersion in deionized water (TH1), groundwater (TH2), and saline water 0.5 w/w g of NaCl (TH3) was respectively calculated using equation 2:

$$Swelling\ ratio = \frac{W_s - W_d}{W_d} \qquad \ldots \text{(Eq 2)}$$

Where W_s is the weight of swollen hydrogel and W_d is the dry weight of hydrogel.

Water retention: The test determines the amount of water released by the hydrogel under various temperature conditions over time. The test was done according to method adopted by (Zhang, Yong et al. 2014). A measured amount of hydrogel was soaked in the solution and kept at 25 ^{0} C for 24h with three types of solution - deionized, groundwater and saline (0.5 % w/w) water were used. The soaked hydrogel was removed from the solutions, filtered with the 180 µm and wiped with tissues gently to remove surface water. The surface dried soaked hydrogel is weighed and placed in the incubator at 35 ^{0} C The equilibrium swelling was recorded at regular time intervals, up to 24 h.

Table 2: Treatment groups and respective representations

Representation	Treatment	Water supply (ml/day-plant)
TC1	Control group without hydrogel	144 ± 14
TC2	With hydrogel	115 ± 14
TC3	With hydrogel	87 ± 14
TC4	Treated with hydrogel	58 ± 14

Comparative assessment of plant growth: Paddy seeds were soaked in water for 12 hours before being sown in separate growth bags at a depth of 3 cm from soil surface. 0.75% hydrogel by weight of seeds was carefully placed along the seeds. 3 such groups were prepared with 20 %, 40 %, and 60 % deficit water supply respectively from the average supply of 144 ml per day per plant. A 4th control group was prepared with no hydrogel applied, and allowed to water log (table 3). surface drip irrigation was used for water supply. A set up similar to that used by (Cannazza et al. 2014) was adopted. The total water supplied for each bag was deduced from evapotranspiration values as per (Tyagi N K et al., 2000). The test was carried out for the first stage of crop growth. The plant height at the end of 3 weeks was recorded for comparative study. ANOVA on the data was carried out based on (David J Weiss 2006) and reported with a significance greater than 95 %.

III. RESULTS AND DISCUSSIONS

Hydrogel Assessment

The results of hydrogel swelling ratio were plotted as graphs of time vs. equilibrium swelling (figure 2). The maximum swelling attained significantly differed for all three cases (TH1, TH2, and TH3) with values of 513.3 (30 min), 188.8 (20 min), and 121.9 (60 min) for TH1, TH2, and TH3 respectively. Initial absorption rate for hydrogel in TH1 was observed to be similar to the sample in TH2. TH3 showed a relatively linear variation in initial stages. After peak swelling, the graph shows a slow decrease of swelling rate. The retention property (figure 3) of hydrogel was represented through a graph of time vs. percentage moisture content with respect to swollen hydrogel. TH1, TH2, TH3 represent deionized water (circle), groundwater (square), and saline water (triangle) respectively.

Table 3: Average plant height (cm) for different groups at 2 weeks after sowing.

Groups	Average plant height (cm)	Number of samples
TC1	17	8
TC2	24	5
TC3	23	9
TC4	28	13

The three cases showed no significant differences in the moisture retained till 8 hours. The retention showed a diverging at 24 hours with retention percentages 63.56%, 66.94%, and 70.73% for case I, II, and III respectively. The retention is low for deionized water and increases with increasing ionic content of water.

Crop growth assessment

Seed treatment: The maximum radicle length observed for paddy seeds was for the seeds amended with 1.25 % of hydrogel. It is imperative that the trials show a Germination Index value upwards of 60% as that is the first test to check for signs of phytotoxicity (Francesco et al., 2015). The values obtained

conformed to such and consistently stayed upwards of 80%. These values are also in concordance with other similar tests done by (Francesco et al. 2015).

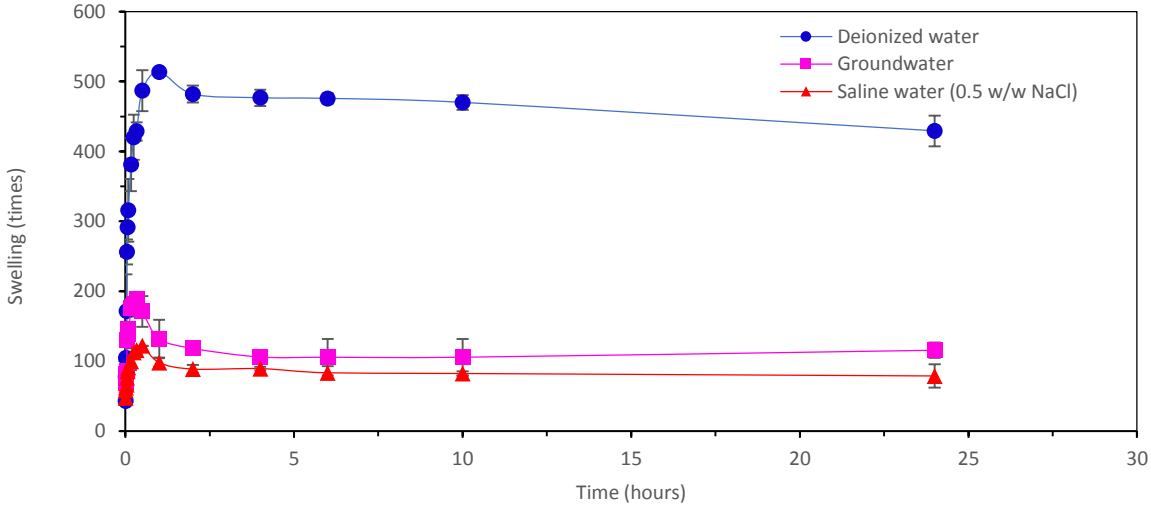


Fig 2: Swelling ratio of hydrogel in deionized water (circle), groundwater (square), and 0.5 % w/w saline water (triangle) reported as a mean of three data points with error bars representing standard deviation.

Crop water requirement comparative study: Table 2 shows the average plant height obtained at 2 weeks after sowing for corresponding number of samples. A gradual trend of increase in plant growth was seen with decreasing water supply and application of hydrogel (figure 4). The least plant height corresponded to the control group (17 cm) and the highest plant height corresponded to treatment group with 60% deficit water supply (28 cm). These effects in paddy can be attributed to several factors - improved root zone moisture retention, improved access to oxygen to plant root as a result of increase in porosity of soil surrounding the roots, and reduced leaching of nutrients from soil through runoff and infiltration. Moreover, deficit irrigation for paddy benefits in more than just saving water.

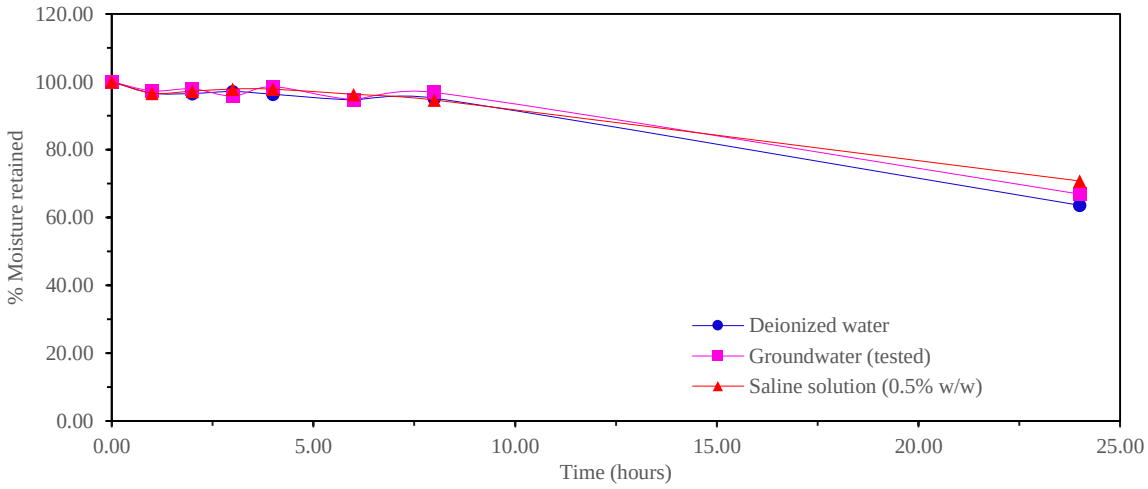


Fig 3: Percentage moisture content in swollen hydrogel in deionized water (circle), groundwater (square), and 0.5 % w/w saline water (triangle) reported as a mean of 3 data points over 24 hours while exposed to 35 ^{0}C

A study in West Bengal by (Sarkar et. al., 2012) showed that deficit irrigation can reduce the uptake of arsenic in paddy. The results of the present study are consistent with growth patterns reported in various studies.

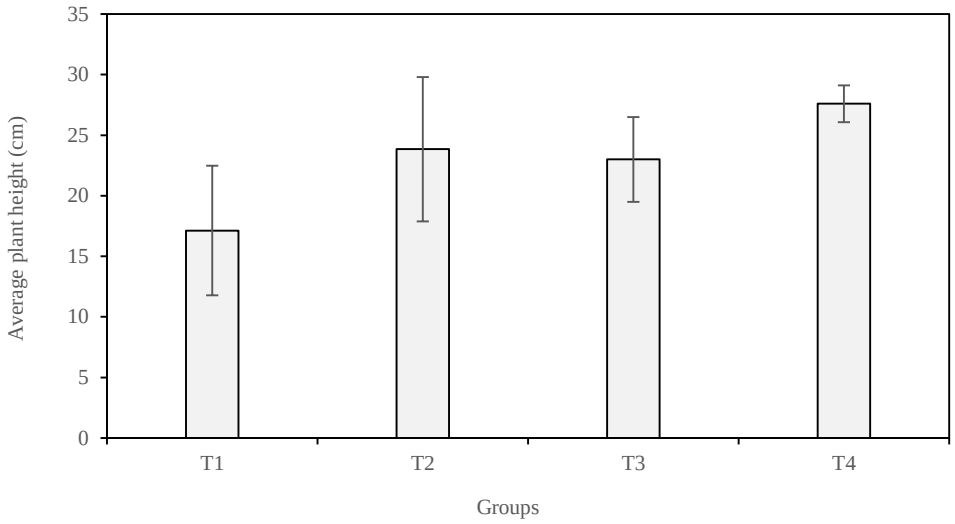


Fig 4: Average plant height of paddy recorded at 3 weeks after sowing for different groups - control excess corresponding to group without hydrogel application; t-20 deficit, t-40 deficit, and t-60 deficit corresponding to groups treated with hydrogel with 20%, 40%, and 60% deficit water supply respectively. The error bars represent standard deviation.

(Parthasarathy et al.2018) showed that aerobic irrigation for paddy gave better yields compared to conventional irrigation methods. (Rehman A et al. 2011) investigated the use of hydrogel for aerobic irrigation of paddy and showed that the yield increased relative to conventional methods. Though plant height cannot be a direct indicator of grain yield, A study by (Ronghua L et al.2019) showed a significant correlation between plant height and grain yield for indica hybrid variety of paddy for a large dataset ranging from 1978 to 2017. Thus, it could be validated that the results of the current study would indicate towards a greater yield in paddy treated with hydrogel for aerobic irrigation method. There has however been indication that the effect of the hydrogel on the rate of growth of the plant in its final stage is close to negligible, possibly due to the fact that water requirement at this stage is relatively less, and thus the amelioration with the hydrogel becomes optional (Francesco et al., 2015). However, there is a need to study this phenomenon further in water stressed areas and of soil types with poor water retention. In this regard, cultivated lands, known to have contamination can use the application of hydrogel as a remedial measure for the improvement of yield during deficit irrigation.

IV. CONCLUSIONS

Water uptake is the functional part of any crop. Once the seed is sowed in the soil the immediate requirement is a favourable condition with sufficient moisture content in the soil. Through hydrogel this was achieved even with deficit water intake. Increased amount of water availability to the seed at the crucial stages of its growth capacitated a high number of germinations and also faster and healthy growth of the plant. Inclusion of hydrogel showed a positive impact on the plant and have shown a greater rate of growth. In paddy with 60% deficit water, the highest plant growth was seen and this surprising trend of increased growth with decreased supply of water, is an interesting find and should warrant more investigation.

Studies on the properties of hydrogel showed that the commercially available hydrogel developed based on potassium polyacrylate is a brilliant candidate for improving the agricultural water use efficiency and consequently the irrigation efficiency. Shocks during dry spells can be prevented with hydrogel. As hydrogel enables deficit irrigation by a large margin, bioaccumulation can be prevented in contaminated cultivable lands. Though this study indicates towards a probable higher yield, validation of the water requirement must be done through field level experiments. There is also a need to experiment on porous soil with less clay content which is more prevalent in arid and semi-arid regions.

The study supports that the use of hydrogel could protect water resources and ensure sustainability in terms of water and food security. Though studies have pointed towards no negative environmental impact of hydrogel in agriculture, the long-term effects need to be addressed in future studies. This again requires a field level substance flow investigation for effects of hydrogel especially in arid and semi-arid regions.

V.ACKNOWLEDGEMENT

Authors acknowledge School of Civil Engineering, Christ Deemed to be University for their support and for providing necessary facilities to carry out this research.

VI.AUTHOR CONTRIBUTIONS

Surya designed methodology, literature review and writing-original draft. Sriram performed data analysis, interpretation and writing-original draft. Girinath contributed in conceptualization. Ankush and Aditya performed experiments and investigation. Shibu and Geetha contributed in supervision and reviewing the analysis in the manuscript.

VII.CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the author.

REFERENCES:

1. Agaba, Hillary, *et al*. "Hydrogel amendment to sandy soil reduces irrigation frequency and improves the biomass of Agrostis stolonifera." Agricultural Sciences 2.04 (2011): 544**.** https://www.scirp.org/html/8549.html

2. Cannazza, Giuseppe, *et al*. "Experimental assessment of the use of a novel superabsorbent polymer (SAP) for the optimization of water consumption in agricultural irrigation process." Water 6.7 (2014): 2056-2069. https://www.mdpi.com/2073-4441/6/7/2056
3. Chandana, S. S, 2019. application of potassium polyacrylate on soybean (Glycine max L.) productivity and soil microbial biomass under rainfed condition. M.Sc. thesis. University of Agricultural Sciences GKVK, Bangalore. https://krishikosh.egranth.ac.in/handle/1/5810151468
4. CWC, Water and Related Statistics, Ministry of Water Resources, Central Water Commission (CWC), Government of India, New Delhi, 2019**.** http://cwc.gov.in/sites/default/files/water-and-related-statistics-2019.pdf
5. David J Weiss. 2006. Analysis of Variance and Functional Measurement. Oxford University press, New York. https://global.oup.com/academic/product/analysis-of-variance-and-functional-measurement-9780195183153?cc=in&lang=en&
6. ECOSOC, UN. "Special Edition: Progress towards the Sustainable Development Goals Report of the Secretary-General." Advanced unedited version. New York (US): United Nations (2019). https://sustainabledevelopment.un.org/content/documents/22700E_2019_XXXX_Report_of_the_SG_on_the_progress_towards_the_SDGs_Special_Edition.pdf
7. FAO-STAT-2019-20. http://www.fao.org/3/ca6463en/ca6463en.pdf
8. Francesco F Montesano, Angelo Parente, Pietro Santamaria, Alessandro Sannino, Fransesco Serio, "Biodegradable Superabsorbent Hydrogel Increases Water Retention Properties of Growing Media and Plant Growth", Agriculture and Agricultural Science Procedia 4, 2015, pages 451 – 458**(.** https://www.sciencedirect.com/science/article/pii/S2210784315001151
9. Guilherme, Marcos R., *et al*. "Superabsorbent hydrogels based on polysaccharides for application in agriculture as soil conditioner and nutrient carrier: A review." European Polymer Journal 72 (2015): 365-385. https://www.sciencedirect.com/science/article/abs/pii/S0014305715002335
10. ICAR report. 2019. Annual report 2019-20. Indian Council of Agricultural Research, New Delhi. https://www.iari.res.in/files/Publication/annual_report/IARIAnnualReportRevised2019_20_30092020.pdf
11. Jacoby, Richard, *et al*. "The role of soil microorganisms in plant mineral nutrition—current knowledge and future directions." Frontiers in plant science 8 (2017): 1617. https://www.frontiersin.org/articles/10.3389/fpls.2017.01617/full
12. Jamnongkan, Tongsai, and Supranee Kaewpirom. "Potassium release kinetics and water retention of controlled-release fertilizers based on chitosan hydrogels." Journal of Polymers and the Environment 18.3 (2010): 413-421**.** https://link.springer.com/article/10.1007/s10924-010-0228-6
13. Jha, Ajay K., *et al*. "Impact of irrigation method on water use efficiency and productivity of fodder crops in Nepal." Climate 4.1 (2016): 4 **.** https://www.mdpi.com/2225-1154/4/1/4

14. Johnson, Michael S. "The effects of gel-forming polyacrylamides on moisture storage in sandy soils." Journal of the Science of Food and Agriculture 35.11 (1984): 1196-1200. https://onlinelibrary.wiley.com/doi/abs/10.1002/jsfa.2740351110
15. Li, Ronghua, *et al*. "Exploring the relationships between yield and yield-related traits for rice varieties released in China from 1978 to 2017." Frontiers in plant science 10 (2019): 543. https://www.frontiersin.org/articles/10.3389/fpls.2019.00543/full
16. Parthasarathi, Theivasigamani, *et al*. "Evaluation of drip irrigation system for water productivity and yield of rice." Agronomy Journal 110.6 (2018): 2378-2389. https://acsess.onlinelibrary.wiley.com/doi/abs/10.2134/agronj2018.01.0002
17. Piao, Shilong, *et al*. "The impacts of climate change on water resources and agriculture in China." Nature 467.7311 (2010): 43-51**.** https://www.nature.com/articles/nature09364?page=12
18. Rehman A., Ahmad R., Safdar M. (2011): Effect of hydrogel on the performance of aerobic rice sown under different techniques. Plant Soil Environ., 57: 321-325. https://www.agriculturejournals.cz/web/pse.htm?type=article&id=81_2011-PSE
19. Roy, Trisha, *et al*. "Impact of Pusa hydrogel application on yield and productivity of rainfed wheat in North West Himalayan region." Current Science (00113891) 116.7 (2019. https://www.currentscience.ac.in/Volumes/116/07/1246.pdf
20. Shooshtarian, S., J. Abedi-Kupai, and A. TehraniFar. "Evaluation of Application of Superabsorbent Polymers in Green Space of Arid and Semi-Arid Regions with emphasis on Iran." International Journal of Forest, Soil & Erosion (2012). http://ijfse.com/uploadedfiles/IJFSEArchive/IJFSE2012/2-1-2012-Feb/4-6-24-36-%20shooshtarian-%20Feb-2012.pdf
21. Tyagi, N.K., Sharma, D., & Luthra, S. (2000). Determination of evapotranspiration and crop coefficients of rice and sunflower with lysimeter. Agricultural Water Management, 45(1), 41–54. https://www.sciencedirect.com/science/article/abs/pii/S0378377499000712
22. Zhang, Yong, *et al*. "An eco-friendly slow-release urea fertilizer based on waste mulberry branches for potential agriculture and horticulture applications." ACS Sustainable Chemistry & Engineering 2.7 (2014): 1871 -1878**.** https://pubs.acs.org/doi/abs/10.1021/sc500204z

Alinteri J. of Agr. Sci. (2021) 36(2): 38-52
e-ISSN: 2587-2249
info@alinteridergisi.com

http://dergipark.gov.tr/alinterizbd
http://www.alinteridergisi.com/
DOI:10.47059/alinteri/V36I2/AJAS21113

RESEARCH ARTICLE

Sustainable Irrigation through Application of Hydrogel: A Review

Surya Prakash[1*] • Sriram Vasudevan[2] • Ankush Banerjee[3] • Aditya C Joe[4] • K.N. Geetha[5] • Shibu K Mani[6]

[1*]*Research Scholar, CHRIST (Deemed to be University), School of Engineering and Technology, Department of Civil Engineering, Bengaluru, Karnataka, India. E-mail: boreddyspr1@gmail.com, ORCID: 0000-0001-9893-2153*

[2]*UG Scholar, CHRIST (Deemed to be University), School of Engineering and Technology, Department of Civil Engineering, Bengaluru, Karnataka, India. ORCID: 0000-0002-4526-4611*

[3]*UG Scholar, CHRIST (Deemed to be University), School of Engineering and Technology, Department of Civil Engineering, Bengaluru, Karnataka, India. ORCID: 0000-0002-7996-021X*

[4]*UG Scholar, CHRIST (Deemed to be University), School of Engineering and Technology, Department of Civil Engineering, Bengaluru, Karnataka, India. ORCID: 0000-0002-6590-0902*

[5]*Department of Agronomy, University of Agricultural Sciences, GKVK, Bengaluru, Karnataka, India. ORCID: 0000-0003-1393-3638*

[6]*Associate Professor, CHRIST (Deemed to be University), School of Engineering and Technology, Department of Civil Engineering, Bengaluru, Karnataka, India. ORCID: 0000-0001-6756-1206*

ARTICLE INFO

Article History:
Received: 27.04.2021
Accepted: 05.06.2021
Available Online: 12.07.2021

Keywords:
Hydrogel
Irrigation
Sustainability
Agriculture
Superabsorbent Polymer
Biodegradability
Slow Release
Absorbency
Swelling
Degradation

ABSTRACT

Agricultural sustainability is essential to enhance food and water security, particularly in the context of climate change. In the recent past, applications of hydrogels in agriculture have received substantial attention among researchers as well as among farmers. This review elaborates on various aspects of hydrogels such as classifications, ideal properties for agricultural application, and interaction mechanisms with soil and plants. The experimental methods for determining hydrogel properties were given specific attention as properties such as swelling, retention, slow release, and degradation are of vital importance to agricultural sustainability. The studies conducted over the years on the effect of hydrogel application on different crops are reviewed. Several hydrogel studies demonstrate significant improvement in water consumption, water use efficiency, crop growth and yield parameters. The review looks into hydrogel degradation mechanisms in soil and also the 'test methods' for assessment of biodegradation. The gap areas in research on hydrogels and agricultural sustainability have also been identified. The need for developing a framework for the evaluation of the suitability of hydrogel for agricultural applications has been brought out. The review would encourage further research on enhancing the ideal properties of hydrogel and synthesizing with natural polymers. The use of hydrogel in agriculture for controlled nutrient release could be an alternative to conventional release methods for fertilizers and pesticides, thereby reducing the environmental footprint. The reduction in water footprint in major crops such as paddy and wheat through hydrogel might establish a shift towards sustainable irrigation practices if adopted on a large scale. Integrating innovative solutions with environmental-friendly hydrogels in the coming decades will contribute to the pursuit of achieving sustainable development goals.

Please cite this paper as follows:

Prakash, S., Vasudevan, S., Banerjee, A., Joe, A.C., Geetha, K.N. and Mani, S.K. (2021). Sustainable Irrigation Through Application of Hydrogel: A Review. *Alinteri Journal of Agriculture Sciences, 36*(2): 38-52. doi: 10.47059/alinteri/V36I2/AJAS21113

Introduction

Water is the most consumed resource on the planet. Scarcity of water is a threat to most nations, and is currently a pressing issue in most developing nations, owing to climate change, and the increasing trend of temperature anomalies (Allen et al. (2018)). Increase in human activities such as agricultural production, and rapid domestication of animals have had a profound impact on the resource balances in the ecosystem of the planet leading to uncertainties in

* Corresponding author: boreddyspr1@gmail.com

climate shifts (Smith & Zeder (2013)). These changes are generally not expected to be distributed equally and will much be dependent on regional climatic variations, resource availability and adaptive capabilities. Moreover, those nations not having participated in the accumulation of greenhouse gases will experience the highest environmental harm from climate change (Lelieveld et al. (2012)).

Extreme temperature events and drought frequency have increased in the recent decades. Several studies have been done with respect to the impact of climate change on precipitation and irrigation. In India, it has been predicted that an increase in irrigation storage is essential to keep the agricultural production at level with the demand due to decline in groundwater reserves in semi-arid regions and shifts in surface water distribution across river-fed irrigation plains (Devineni et al. (2013)). It is claimed that the number of drought events over the past decade has worsened and the pattern of monsoon rainfall contributing to 80 % of Nepal's precipitation has become more erratic since 2000 (Jha et al. (2016)). Each year has been hotter than the previous year in the African continent for the past 20 years. It is estimated that by 2080, the average temperature across Africa would increase by 4.5 °C with drastic changes in precipitation patterns (Rosenstock et al. (2018)). In China, the predictions show that there will be a temperature increase of at least 1.5 °C by the year 2100, and the precipitation would be increasingly unpredictable and more erratic with increased frequency of droughts and floods in the coming years besides more possibilities for heatwaves (Piao et al. (2010)). Depletion and scarcity of water poses a major obstacle towards development. Agricultural sector is the largest consumer of water and would come to bear the greatest blow from water scarcity issues (Roy et al. (2019)).

The "sustainable development goals" (SDGs), and "climate-smart agriculture" (CSA) are guiding frameworks for establishing sustainability in terms of food security, water availability, and production and consumption (Rosenstock et al. (2018), ECOSOC (2019)). It is reasonable to reduce consumption while increasing crop production to overcome the issues of excess consumption and reduced yield. Soil moisture and soil nutrient content are major deciding factors to ensure high yield of crops. Intermittent absence of water for crops such as paddy can lead to heavy losses for the farmers as well the society. Continuous supply of water under ordinary conditions is a necessity for the cultivation of such crops. In semi- arid regions, the crops such as paddy and wheat cultivated are either rainfed or through canal irrigation (Devineni et al. (2013)). The availability of water for rainfed rivers is uncertain with changes in precipitation patterns due to climatic variations. It is important to look into alternatives which can contribute to a better crop production environment with the help of sustainable water use approach. The quantity of water consumed by crops mainly depends upon the irrigation methods, Agro-meteorological parameters such as evapotranspiration, and the soil properties (Jacoby et al. (2017)). The conventional method of irrigation - furrow irrigation, is shown to have a high rate of evapotranspiration, low grain yield, and high erosion and leaching of soil from cultivated land (Sarkar et al. (2012), Bhattacharya (2018)). Around 40% of the world's freshwater is consumed by conventional irrigation methods in the production of rice (Parthasarathi et al. (2018)).

To reduce water consumption, control over irrigation practices and soil conditions could be possible. Irrigation planning is usually done to ensure that the amount of water supplied to the plants maintains a balance between the available water for plants in the growth medium (soil, mostly) and the amount of water consumed by the plant for growth and transpiration. The factors that can be considered to maintain the balance are the soil-water potential and the available water in the soil (Agaba et al. (2011)). Prediction models for short and long-term water resource management in irrigation have been developed. Ines et al. (2006) combined remote sensing-simulation modeling and genetic algorithm optimization to explore water management options in irrigated agriculture.

Surface drip irrigation and subsurface drip irrigation have shown to reduce water consumption by at least 70% (Smith & Zeder (2013)). (Parthasarathi et al. (2018)) showed that an aerobic drip irrigation system for rice cultivation could give a 39% higher economic return with a 49% reduced water consumption. Although subsurface drip irrigation is a very efficient irrigation method, it has had relatively limited expansion due to several disadvantages such as the clogging of emitters, difficulty of detecting leakages and repairing them (Frantz et al. (2005)).

An alternative approach is the use of soil conditioners. They help in reduced soil erosion, water retention in soil, reduction of high infiltration rates, prevention of fertilizer and pesticide runoffs, and reduction of evaporation of water in irrigated lands. Recently, several studies have been done towards the use of soil conditioners in regions with water scarcity and low precipitation (Narjary et al. (2012)). Farming communities began to use manure (organic matter), straw mulch, bitumen (treated and untreated), bitumen emulsions as soil conditioners but as time progressed, they have started using polyacrylamide (PAAm), a hydrophilic polymer (Tayel & El-Hady (1981), De Boodt (1975)). PAAm was first reported to be used for highway embankment stabilizations using plant growth in France, where dry unfertile lands were turned to well established vegetations (De Boodt (1975)). Studies were done in 1976 using a gelating material under the name verdyol for soil conditioning. Tayel & El-Hady (1981) proposed a supergel - a hydrophilic polymer which forms gel immediately on contact with water, for soil conditioning in sandy soil. These studies showed that hydrophilic polymers with swelling properties had the capacity to be built into soil conditioners. These materials were later developed into hydrogels which were originally developed for their applications in the medical industry (Bruck (1973), Kazanskii & Dubrovskii (1992)). Hydrogels can be defined as three-dimensional polymeric networks that can retain a significant amount of water within their structures and swell without dissolving in water (Jamnongkan & Kaewpirom (2010), Guilherme et al. (2015)). By modifying the functional groups during synthesis, hydrogels could be adapted for use as soil conditioners. Soils that are amended with hydrogel show higher water retention. In most studies, an increasing concentration of hydrogel shows higher

water retention in soils (Demitri et al. (2013)). Hydrogel can act as a water reservoir for plants, and its slow-release properties can be used to supply micro and macro nutrients to enrich the soil (Jamnongkan & Kaewpirom (2010)). Its degradation products can be engineered to improve the nutrient content of the soil, and thus promote the growth of symbiotic organisms in the soil (Abd El- Rehim (2006), Devineni et al. (2013)). The advantages and limitations towards sustainability associated with the use of hydrogel with respect to plant growth, and interactions with microbiome, soil and water are presented in this study.

Classifications of Hydrogel

Classification is necessary for a focused study of any material. Several hydrogel classifications have been documented by researchers (Kazanskii & Dubrovskii (1992), Ahmed (2015), and Ghobashy (2020)). The hydrogel classifications based on source, synthesis, crosslinking, and pore size are discussed in this section.

Classification based on Source

Hydrogels are formed by the crosslinking of polymers that are either naturally occurring or synthetically produced. The source-based classification is shown in figure 1. The earliest hydrogels used for agricultural purposes were synthetic, such as polyacrylamide, polyvinyl alcohol and polyethylene oxide (Kazanskii & Dubrovskii (1992)) which later were realized to pose potential environmental hazards (Zhang et al. (2014)). The synthetic hydrogels are known to possess high swelling degree, high durability, and slow degradation (Ahmadi et al. (2015)). Natural polymer-based hydrogels however have a low structural strength and a low swelling degree. However, natural-polymer based hydrogels are biodegradable (Ahmadi et al. (2015)). In some cases, the degradation products even enrich the soil. To combine the advantages of both natural polymer-based hydrogel and synthetic hydrogel, the natural polymers can be crosslinked onto synthetic polymers, giving rise to a new set of hydrogels.

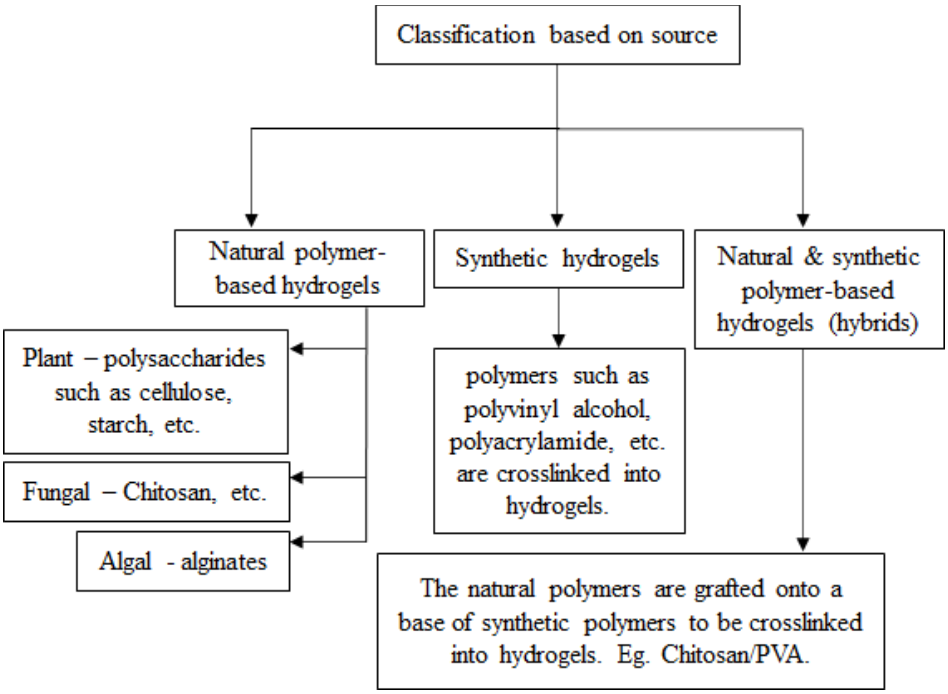

Classification based on source
Natural polymer-based hydrogels
Synthetic hydrogels
Natural & synthetic polymer-based hydrogels (hybrids)
Plant – polysaccharides such as cellulose, starch, etc.
Fungal – Chitosan, etc.
Algal - alginates
polymers such as polyvinyl alcohol, polyacrylamide, etc. are crosslinked into hydrogels.
The natural polymers are grafted onto a base of synthetic polymers to be crosslinked into hydrogels. Eg. Chitosan/PVA.

Figure 1. Source-based classification of hydrogel (Ghobashy (2020)).

For agricultural applications, cellulose based hydrogel is prepared from its derivative - cellulose ethers which show biodegradability, and non-toxicity (Ghobashy (2020)). carboxymethyl cellulose and hydroxyethyl cellulose (Montesano et al. (2015), Cannazza et al. (2014)) are examples of cellulose ethers. Novel hybrid hydrogels based on starch, chitin, tulip extracts have shown promising results in terms of swelling and degradability (Xiao et al. (2017), Kollar et al. (2016), Zhang et al. (2014)).

Classification based on Synthesis Method

Several synthesis methods of hydrogel have been reported in literature. Potentially, any polymerisation technique that produces crosslinks could be incorporated into hydrogels preparation. Specifically, solution polymerisation, graft polymerisation, radiation induced radical polymerisation, bulk polymerisation, and inverse suspension polymerisation are widely used and considered as a broad methodical classification as shown in figure 2 (Ahmed (2015)). Grafting to support polymerisation is discussed in detail in by Latif et al. (2016). They made attempts to combine chitosan-based hydrogel with PAAm, and PVA (polyvinyl alcohol). Solution polymerisation is well described by Kollar et al. (2016), where homopolymerisation, and copolymerisation are carried out with a compound known as tulipalin A (tulip extract derivative). Bulk polymerisation results in the formation of a single large matrix which can be prepared in the desired shape (Ahmed (2015)). Radiation induced crosslinking is done by irradiating the monomer units with high energy

radiation such as gamma rays, X-rays, and electron beams. A study by Katayama et al. (2006), used Acacia senegal seeds for preparing hydrogel by using electron beams of different strengths. The method of synthesis and the concentration of crosslinking agents and initiators involved in the chemical reactions determine the resulting properties of the hydrogel such as swelling degree, resistance to temperature, and response to pH Guilherme et al. (2015), Ahmed (2015)).

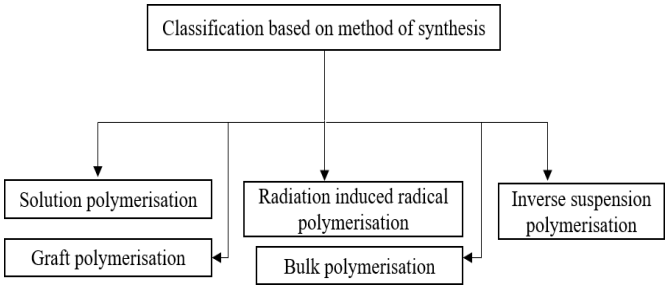


Figure 2. Synthesis methods (Ahmed (2015), Kazanskii & Dubrovskii (1992)).

Classification based on Crosslinking

Crosslinking is a key factor that enables the polymers to form three dimensional matrices which are elastic in nature allowing swelling as well as providing stability to the structure of the matrix. The classification based on crosslinking is shown in figure 3. Chemical crosslinking is permanent and gives strength and durability to the hydrogel. This is an advantageous property for applications under high temperature, varying pH, and pressure. Physical crosslinks are reversible because of its ready response to destabilize under external environmental stimuli. This is a limitation of physical crosslinking. However, the response to external stimuli is an advantage for the hydrogel to be used as a smart material in various applications such as moisture sensors and pH sensors (Shin et al. (2010), Tellis et al. (2011)). The swelling degree of the prepared hydrogel is mainly based on crosslinking density in a given unit of hydrogel matrix. Since higher crosslink density means lesser length of polymeric chains, and lesser elastic limit, swelling degree is inversely proportional to the crosslink density (Guilherme et al. (2015)). This is discussed in detail in section 3 of the review.

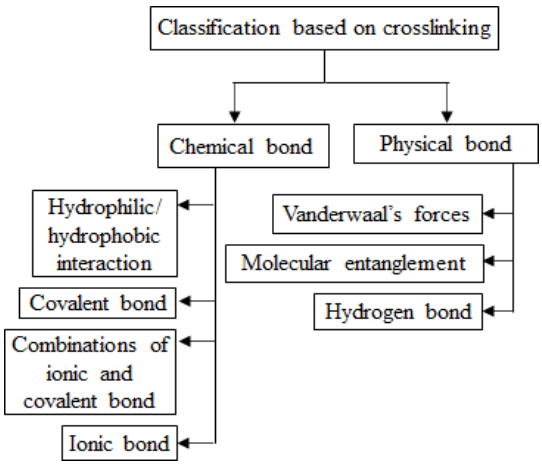


Figure 3. Crosslinking modes (Ahmadi et al. (2015)).

Classification based on Pore Sizes

Pore size is an important property in hydrogels used for drug delivery and has been dealt in detail by respective researchers Ahmed (2015), Omidian et al. (2005), Ahmadi et al. (2015). The classification based on pore sizes is shown in fig 4. In agricultural, the swelling rate is not the governing factor for application. Rather, swelling ratio, slow-release kinetics, and biodegradability are considered during synthesis. Thus, a glassy matrix with absorption of a few hours (Parthasarathi et al. (2018)) can still effectively deliver in soil for agriculture.

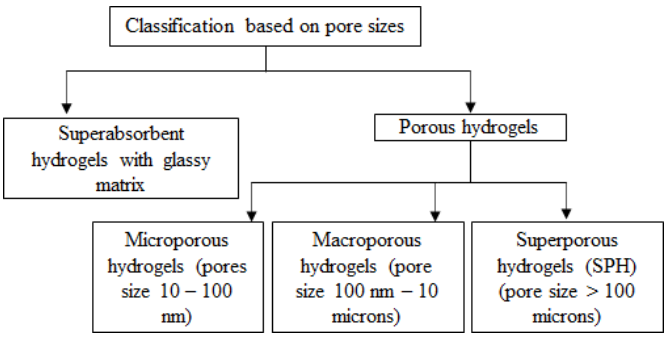

Classification based on pore sizes
Superabsorbent hydrogels with glassy matrix
Porous hydrogels
Microporous hydrogels (pores size 10 – 100 nm)
Macroporous hydrogels (pore size 100 nm – 10 microns)
Superporous hydrogels (SPH) (pore size > 100 microns)

Figure 4. Pore-size based classification (Chen et al. (1999)).

Stimuli Responsive Hydrogel

Stimuli responsive hydrogels (SRH) are a class of smart superabsorbent polymers that change one or more of its properties as a response to a particular change of any of the environmental parameters such as temperature, overburden pressure, pH, ionic concentration, osmotic pressure, and electromagnetic field (Rehman et al. (2011)). Ahmed (2015) mentions SRH that can be applied in biological, and physical processes for a variety of applications. Advances in SRH are mainly developed into biosensors for drug delivery, textiles, and micro electromechanical systems (Stuart et al. (2010)). Biocatalytic systems coupled with hydrogel membranes that deliver specific enzymes in response to biochemical signals and reactions facilitates fast drug delivery and transport (Tokarev et al. (2009)). A good photonic crystal hydrogel is one which undergo a change of colour in response to change in pH. An interpenetrating photopolymerized hydrogel showed a colour change within 10 to 20 seconds for pH ranging from 3 to 6 (Shin et al. (2010)). The absorption of water by hydrophilic polymers in the hydrogel matrix could be used in monitoring the water content of the surroundings. Such a sensor is mentioned in recent literatures. Agarose based hydrogel films incorporated with dapoxyl sulfonic acid (fluorophore) changed over a range of 30 to 40 nm wavelengths for a 0 % to 100% change in air humidity and gaseous medium with a 15-minute response time (Tellis et al. (2011)). Tellis et al. (2011) points out that the use of environment sensitive fluorophore rather than the polymer chains or crosslinkers for detection of environment change enables the incorporation of this property into a variety of hydrogels to be used as smart materials. This opens the scope for studies that can exploit the properties for agricultural applications such as moisture-based release systems, time-based fertilizer release systems, and enzyme-based pesticide/fungicide systems.

Properties of Hydrogel

Ideal Properties for Agriculture

It has been highlighted that the traditional forms of irrigation in India, such as check basin and furrow types, failed to perform in a sustainable manner, as they induce wastages such as evaporation losses, and losses of nutrients from fertilizers due to leaching, to list a few (Parthasarathi et al. (2018)). The properties of hydrogel considered in this section largely pertain to characteristics mediation of which would effectively improve soil and agriculture performance. The categories were chosen on the basis that water and nutrient delivery should be optimized, while the effective use of hydrogel over the field should be reduced, to save resources in the form of water, fertilizers and capital. The characteristics of hydrogel for agricultural applications could be drawn as follows (Ahmed (2015), Neethu et al. (2018)):

- The swelling degree must be high enough so as to reduce the application of superabsorbent polymer (SAP). The swollen size of the hydrogel must not hinder the aeration pores of the soil structure. Thus, a compromise in the swelling degree of hydrogel must be made to ensure that there is no detrimental effect on the aeration pores.
- The structure of hydrogel must withstand the mechanical pressure from the soil and pore water surrounding it. Synthetic polymers provide durability, as the degradation of synthetic polymers is low. Thus, a partnership between the use of natural polymers for degradability and eco-friendliness, and synthetic polymers for durability for the required time must be made.
- The hydrogels must be capable of slow release of water and fertilizers. The slow release must be predictable to control the management of water for optimization. The nutrient release must adhere to a predictable fashion irrespective of environmental changes.
- The hydrogel must act as bio inoculants that enrich the microbial population that contribute to symbiosis is the soil.
- The hydrogel must be biodegradable. The degradation products should bear no toxicity to the biota. The degradation products should enrich the soil fertility.
- In view of this, the properties of swelling, slow release, impacts on soil-plant-microbe, and degradation of hydrogel are discussed in this review. As seen earlier in section 2.2 and 2.1, the properties and behaviour of hydrogel are mainly dependent on the material with which it is made, and the process of synthesis. Cellulose based hydrogel prepared from free radical graft polymerisation of acrylamide and acrylic acid onto cellulose from mulberry branch extract shows a swelling degree of 500 (Zhang et al. (2014)). Cellulose based hydrogel prepared from solution copolymerisation of carboxymethyl cellulose/Na showed a maximum swelling degree of about 200 (Sannino et al. (2010)).

Adopted assays for quality assessment of hydrogels are as follows:

- Encapsulation efficiency: The test is carried out to determine the amount of fertilizer encapsulated in the hydrogel with respect to the amount of fertilizer dissolved during synthesis. (Jamnongkan & Kaewpirom (2010)) uses the equation 1.

$$\eta = \left[1 - \frac{\gamma'}{\gamma}\right] \times 100 \quad (1)$$

where γ' is the unencapsulated amount of fertilizers, γ is the total amount of fertilizers, and η is the encapsulation efficiency.

- Fertilizer release in water: 75 ml of water is dissolved with controlled release fertilizers (CRF) and 30 ml of water is taken out for testing every 24 h, for atomic absorption spectrophotometry to obtain the amount of potassium in the sample. Additional 30 ml is added to it to maintain water availability (Jamnongkan & Kaewpirom (2010)).
- Water absorbency: There are different methods to determine the water absorbency or swelling (times) or swelling degree (%). Jamnongkan & Kaewpirom (2010) and Latif et al. (2016) both reported the following method: The dry hydrogel is weighed and immersed in deionised water. At regular time intervals, the swollen hydrogel is taken out, wiped gently on the surface with tissue/filter paper to remove excess water, weighed and re-immersed in the water. The formula used is 2.

$$\text{Degree of Swelling SD\%} = \frac{W_s - W_d}{W_d} \times 100 \quad (2)$$

Where W_s is the swollen weight and W_d is the dry weight of hydrogel (Jamnongkan & Kaewpirom (2010), Latif et al. (2016)).

- Water retention in soil: 100g of soil is taken in two vessels of known weight each, one with hydrogel and the other without. The amount of water poured in them should be same and should be kept under identical conditions. The weight of the soils is taken in regular intervals (24 hours) for 30 days (Jamnongkan & Kaewpirom (2010)). Percentage water content in each day is calculated to get the moisture release curve.
- Water holding capacity of soil: Several pots are filled with measured amounts of soil, with different concentrations of hydrogel, and one without hydrogel (control). Water is filled until percolated water comes out through the holes. Re-watering is done thrice to ensure maximum swelling of hydrogel. The formula used is water holding capacity (WHC) is as given in equation 3.

$$\%\text{WHC} = \frac{W_s - W_d}{W_d - W_p} \times 100 \quad (3)$$

Where W_s is weight of a pot with water saturated soil, W_d is weight of a pot with dried soil, and W_p is weight of pot without soil (Rychter et al. (2019)).

Chitosan hydrogel has high biodegradability and low swelling due to low relaxation rate of polymer chains. A study done by Jamnongkan & Kaewpirom (2010) compared the swelling of hydrogel produced by only PVA (synthetic), PVA/Chitosan blend, and only chitosan (natural); the results showed that swelling was of the order PVA>PVA/CS>CS. A blend is necessary to incorporate biodegradability and high swelling. For their success under Indian conditions, the key requisites include their workability in harsh tropical and subtropical climates, particularly with respect to higher temperature conditions, and a sustained release of water from their matrices for use by plants. Re-wetting capability, if required, the hydrogel has to be able to give back the

imbibed solution or to maintain it; depending on the application requirement (e.g., in agricultural or hygienic applications) (Ahmed (2015)).

Swelling Properties

Swelling refers to the property of the hydrogel to retain water as a virtue of its crosslinking and hydrophilicity. As these hydrophilic groups helps hydrogel to absorb water molecules which in turn expands the 3D matrix, this is also known as swelling. The Degree of swelling therefore can be attributed to the number of linkages that the particular hydrogel harbours (Jamnongkan & Kaewpirom (2010), Ahmadi et al. (2015)). The swelling of the polymerized gum arabic was estimated according to the Japan Industrial Standard (JIS) K7223. The initial dry weight of the hydrogel is measured, and immersed into the solvent for a 16–24-hour period (for maximum swelling). Subsequently the hydrogel is drained through a mesh (the pore size varies from 80 - 150 micrometer). Weight of the final residue is measured and equation 2. Swelling properties measured as a function of time can be measured using the equation 4

$$\eta_t = \frac{\sigma_{t=0} - \sigma_t}{\sigma_{t=0}} \times 100 \quad (4)$$

where the $\sigma_{t=0}$ is the initial concentration of the solute without the hydrogel, and σ_t is the final concentration after a set period of absorption of the selected hydrogel (Guilherme et al. (2015)). This may provide an insight into the initial response of hydrogel in the solvent and could be a preliminary assay to check the loading capability or, in this case, swelling (Guilherme et al. (2015)). Fumio et al. (1990) and Ahmadi et al. (2015) also derives the swelling ratio as a function of inverse proportion of its cross-linking density upon polymerization, with the explanation that the presence of larger spaces within the hydrogel structure helps it hold greater amount of water in the empty pockets. As the cross-linking in the matrix intensifies, the Poisson's ratio reaches 0.5. It causes a reduced swelling degree of the matrix (Pritchard & Terentjev (2013), Körner et al. (2009), Paul et al. (2014)). To measure the degree of cross-linking or effective cross-linking density can be formulated using Flory and Rehner's equilibrium swelling theory 5.

$$[\ln(1 - V_2) + V_2 + \chi V_2^2] = \frac{V_1}{V \cdot M_c}\left(1 - \frac{2M_c}{M}\right)\left(V_2^{\frac{1}{3}} - \frac{V_2}{2}\right) \quad (5)$$

Where V_1 and V_2 are the volume fraction of solvent and polymer in the matrix, x is the Flory solvent-polymer interaction parameter, V^{l} is the specific volume of the polymer, M

is the primary molecular weight of polymer (before the crosslinking process) and M_c is the average molecular mass between crosslinks or the network parameter (Guilherme et al. (2015)). The ability of hydrogel to swell or shrink can be controlled to an extent as they display drastic changes in this property as a response to external physical and chemical stimuli such as temperature, pressure, sound, pH, solvent composition, ionic strength and molecular species (Ahmadi et al. (2015), Fumio et al. (1990)). The importance of the polymer backbone with respect to the amount of hydrophilic functional groups it carried was explained by Murphy et al. (1992), by comparing homogeneous poly (acrylic acid) with 1% ethylene glycol dimethacrylate cross linking containing pendant carboxylic acid groups and homogeneous poly (2-hydroxyethyl methacrylate) polyHEMA at similar crosslink densities exhibiting equilibrium water capacities (swelling) at 73% to 38%, respectively.

Fumio et al. (1990) has also shown how the number of freeze-thaw cycles involved in the production of hydrogel also have an impact by ultimately changing the swelling potential. The amount of PVA not incorporated in the hydrogel decreased from 10.6% to 7.0% when subjected to 4 freeze-thaw cycles. The connections between the polymers also appeared much more rigid as the number of cycles increased, as shown through Scanning Electron Microscope (SEM) imaging. This also resulted in a noticeable reduction of swelling over increase in the number of cycles. Furthermore, the degree of swelling of the PVA hydrogel appeared to have a distinct correlation with reciprocal absolute temperature and increased almost linearly at most temperatures. Expansion of the polymeric chain or swelling can be credited to the phenomenon of migration of solvent molecules into the cross-linking polymer. Due to the increase in the solvent concentration inside the polymeric chain, mostly a cause of osmotic force, the ionic repulsion increases which consecutively aids in enlargement of the matrix. Polymeric chain, in opposition to the ionic repulsion, is held together by the elastic retractive forces. The maximum swelling occurs when the equilibrium state (i.e., the net force acting on the matrix becomes zero) is achieved (Guilherme et al. (2015)). As expansion of the polymeric chain depends on the water diffusivity, it is then basic to study the diffusion mechanics of water into the matrix. Using Fick's law of diffusion, the mass transfer is measured for a given period of time through a given medium/space. The following formula is the basic principle of Fick's diffusion law 6.

$$J = -K \times \frac{dQ}{dx} \quad (6)$$

where flux J is the Net rate of particles moving through an area, Gradient $\frac{dQ}{dx}$ is the change in pressure or concentration over a length and diffusion coefficient K is the ratio of Solubility to the square root of the molecular weight (Brazel & Peppas (1999)). A derivative of the aforementioned formula has been derived as an empirical relation to explain the diffusion kinetics is Korsmeyer-Peppas model (power law) 7:

$$\frac{M_t}{M_{eq}} = Ct^n \quad (7)$$

where M_t is the amount of water absorbed/nutrients released at time t, M_{eq} is the amount of water absorbed/nutrients released at equilibrium, C is the characteristic constant, n is the diffusion exponent characteristic of the absorption/release mechanism (Jamnongkan & Kaewpirom (2010)). Table 1 gives a brief on the type of diffusion in correlation with the value of the diffusion constant. Superabsorbent Polymers (SAPs) and Superporous Hydrogels.

Table 1. Range of values of diffusion exponent for different mechanisms of diffusion (Jamnongkan & Kaewpirom (2010))

Diffusion exponent	Diffusion characterics
n<0.5	Quasi-Fickian
n=0.5	Fickian
0.5<n<1.0	non-Fickian
n=1.0	Case II transport

(SPHs) are relatively newer classes of polymers. The main difference between these two lies in the diffusion mechanisms by which the water enters the hydrogel network. SAP and SPH both exhibit relatively very fast swelling properties upon the application of water, however the former is largely dependent on the size of the particles or samples in their initial dry states. As the diffusion constant is inversely proportional to the molecular weight of the solvent, the diffusivity of such particles has considerable difference. SPH overcomes this problem by the virtue of the interconnected open channels they have in their matrices which allow the water to flow in, regardless of the size of the sample. The pore sizes in SPHs range in the order of hundreds in their dry states (Chen et al. (1999)). Another difference observed was that, toward the end of the drying process where control over the final drying of SAP is very critical as it affects its final swelling properties, unlike the process for SPHs, where the polymerization process is limited to the time of gel formation (Omidian et al. (2005)). Latif et al. (2016) studies the swelling of differently prepared hydrogels over time, showing a distinct superiority of the equilibrium of a hydrogel prepared by graft copolymerization of acrylic acid (Pg) on PVA, explaining this phenomenon by the fact that the –COOH groups in hydrogel molecular structure acted as excellent hydrophilic groups, and thus facilitated higher concentrations of water inside in the matrix, also recommending that this required further research. Certain applications also required fast swelling of hydrogels, and these have been widely explored too. Chen et al. (1999) derived hydrogel for drug delivery whose fast swelling, preferably in 5 – 30 min. The tiny interconnected pore spaces behaved as capillary tubes (open channels) within the dry hydrogel matrix, which allowed the water to diffuse rapidly. This could be explained for SAPs as a two-phase process where water molecules are first accumulated on the outer layer, creating a state of duality of dry hydrogel and partially swollen. Water continues to diffuse into the hydrogel pores towards its centre. SPHs bypass the first process due to the continuous movement of water through its channels immediately, resulting in faster swelling (Omidian et al. (2005)). Many studies have indicated a change in equilibrium swelling potential over hydration and rehydration cycles, mostly notably in agriculture related studies. This could be attributed to the increasing salinity of water, due to fertilizer and soil-water salt interactions, being absorbed by the hydrogel themselves (Cannazza et al. (2014), Demitri et al. (2013)). Division in the H- bonds due to low pH, resulted in increased swelling degree in chitosan-based hydrogel (Jamnongkan & Kaewpirom (2010)).

Water Retention Properties

For agricultural purposes, an ideal hydrogel would ideally be averse to degradation and hold water under loading conditions and for longer periods of time, in order to deliver water to the plant root hairs only under the latter's potential. This is one reason SAPs are used in agricultural facilities as the amount of water retained under pressure is relatively exceptionally high (Omidian et al. (2005)). SAPs prepared as nonporous hydrogels find remarkable applicability in agriculture as this property also imparts mechanical stability to the polymer and prevents breakdown under sustained soils loads when dispersed in it (Omidian et al. (2005)).

To determine the capacity of the SAP to act as soil conditioner, the SAP samples are submitted into an environment in which the difference in pressure between the soil and the root of vegetables is simulated. A way of doing this is to measure the water uptake at different pressures. The hydrogels are added into a vessel with Richard membrane-covered walls. The water is withdrawn from hydrogels by increasing the pressure of the vessel. The data of water content can be obtained as a function of water retention (given in kg water per kg hydrogel) under pressure given in hecta Pascal (hPa) (Guilherme et al. (2015)). The release kinetic can be changed by adding inorganic particles into hydrogel. The particles, when sufficiently dispersed, cause a tortuosity effect that disturbs the release of solutes. Such an effect gives longer pathways that difficult the diffusion of the solute toward the outside hydrogels. The particles play a role as a retardant factor for drug release (Guilherme et al. (2015)). Studies have however shown exceptional advances in this specific trait. Chen et al. (1999) developed hydrogels for oral drug delivery that showed resilience for 24 to 60 hr in canine stomachs.

Experiments conducted by Cannazza et al. (2014) show the water retaining capability through its release of a synthetically manufactured hydrogel swollen with tap water to be higher after the 5th day than distilled water, speculating that the fixed electrostatic charges on the polymer network. The presence of mineral clay on hydrogels without the hydrolysis treatment, delayed the nutrient (e.g., urea) desorption in quite a significant way. However, an important factor was that, for the hydrolyzed hydrogels, desorption time and the amount of nutrient desorbed increased significantly (Guilherme et al. (2015), Ismail et al. (2013)). As reported in a study focused on the same class of hydrogel used in the present research, the hydrogel swelling is reduced with increasing electrical conductivity; therefore, we can expect a reduced ability to improve the water retention capacity of the substrates in actual cultivation conditions, especially when the substrate electrical

conductivity tends to increase with the progress of the crop cycle (Montesano et al. (2015)).

Slow-release Properties

Studies indicate that the dominant contributor for surface water eutrophication and groundwater nitrate enrichment is the uncontrolled release of agricultural nutrients, herbicides and pesticides on soils. The most crucial and indispensable nutrients for planting soils include potassium, calcium, iron, copper, nitrogen, phosphorus, sulfur and boron, although it is estimated that around 40 - 70 % of nitrogen and 50 - 70 % of potassium are lost by leaching. High quantities of nutrients are not absorbed by plant roots. Thereby, the main aim of using coated fertilizer granules and crosslinked chemically polysaccharide-based hydrogels in the controlled nutrient release on soils is the decreasing the loss of nutrients by leaching and mitigating environmental problems (Guilherme et al. (2015)). Moreover, the use of controlled release fertilizers causes an increase in their efficiency, reduces soil toxicity, minimizes the potential negative effects associated with overdosage and reduces the frequency of the application. Two methods, post and in situ loading have been reported for the loading of nutrients onto the polymer matrix. The in-situ approach is preferred over post-loading one because of the greater loading efficiency. Jamnongkan & Kaewpirom (2010) reported a high efficiency of more than 99% for in-situ loading. The water within the hydrogel dissolves the nutrient, which can diffuse through the polymer network. The movement of solutes toward the outside of the hydrogel can be related with swelling rate. Only a small amount of the load is released. As a result, a portion of loaded solute is preserved when the hydrogel dries in the intervals of irrigations or rains. The release is again activated in the further watering processes, thus providing a prolonged release process that can prevent the leaching. It is also possible to load two or more active substances onto hydrogel so that each one of them may have specific release kinetic. The fraction of nutrient, herbicide, pesticide or other solute released from chemically crosslinked hydrogels may be calculated as given in equation 8 (Guilherme et al. (2015)):

$$Fraction\ release = \frac{Amount\ released}{Amount\ loaded} \quad (8)$$

The release profiles from coated granules are divided in three main steps: i) initial stage with no significant nutrient release, ii) constant release from medium intervals, and iii) gradual decay of the release rate from the longer release period. A mathematical model based on Fick's second diffusion law, based on the nutrient release profiles as a time function, was developed to predict the release rate of polymer-coated fertilizer using a numerical solution and Fourier series expansion. The release time t' during the initial stage was defined by the equation 9

$$t' = \frac{(\gamma r l)}{3P_h \Delta P} \quad (9)$$

where γ is the total granule porosity including also voids between the nutrient core and the membrane; P_h is water permeability of the membrane (in $mm^2\ Pa^{-1}\ Day^{-1}$); P is the vapor pressure difference between water and saturated nutrient solution (in Pa); and r is radius of diffusion (in mm) in the coated granule (Guilherme et al. (2015)). The nutrient release process is attributed to the diffusion behavior of the hydrogel itself, where the fertilizer is encapsulated within a water medium inside the hydrogel, and is released alongside it when the hydrogel starts de-swelling, as illustrated by (Ghobashy (2020)). It has also been insinuated that Smart Biodegradable Hydrogels are used to coat fertilizer in order to control the release of nutrients, which vary according to certain parameters themselves, like the temperature of the media, observing a higher release for increasing temperatures. Pure polysaccharides degrade very quickly in soil, and therefore cannot be used as nutrient carrying vehicles (Zhang et al. (2014)). Therefore, they are processed to make semi-synthetic hydrogels, as discussed earlier. Natural polymers such as starch and cellulose are used to coat fertilizer granules such as Urea in order to make slow-release nutrient derivatives (Ghobashy (2020)). Hydrogel coatings that release only 15% of the total Urea after 1-2 days of application have also been derived, in order to minimize undesirable fertilizer leaching into the soil (Zhang et al. (2014)).

Soil - hydrogel Interaction

Impact on Soil Properties

Hydrogel improves the water retention of soils in arid and semi-arid zones, and supplements agriculture by increasing the amount available in the root zone depth to plants, further increasing the amount of time between successive irrigations. Soil - water relationships are quantified by parameters such as soil water potential, soil water capacity (SWC), available water capacity (AWC), and readily available water capacity (RAWC). Soil water capacity could be calculated from the guidelines given in IS 2720 (1983) and other standards. The available water capacity of soil is calculated from the amount of water removed from suction between the pressures of 30 kPa and 1500 kPa. The readily available water capacity of soil is measured from the difference in water content at 10 kPa and 100 kPa (Narjary et al. (2012)).

In a study done by Narjary et al. (2012), different types of soil were treated with 0.4% and 0.7% hydrogel by weight. The AWC and RAWC water for the control group of the soils and the treated soils were measured. In all, the values of SWC were highest for the 0.7% mix of hydrogel and soil. The hydrogel treated soil reached critical soil water capacity only after 22 days in sandy soil (Narjary et al. (2012)). In a study by Agaba et al. (2011), the water retention was so high that for a period of 69 days, the soil required watering just once in the beginning to sustain the grass species Agrostis Stolonifera. Montesano et al. (2015), have shown how the application of 1-2% w/w of hydrogel in sandy soils (91.5% sand, 4.2% silt and 4.3% clay) had a very positive impact on it by doubling, and even quadrupling the soil water holding capacity, making it comparable to even silty clays and loamy soils (Katayama et al. (2006)). Rychter et al. (2019) showed through experimental analysis of soil-water-hydrogel setup by conducting water holding capacity test and water retention test. The results from this study by Rychter et al. (2019) show significant increase in the water holding capacity of soils with high hydrogel content (0.1% w/w), and the water retention

was at least thrice that of the soils without hydrogel. Soil conditioners based on naturally occurring polymers such as guar have been shown to prevent surface crusting of soil (Wallace (1986)).

Hydrogels provide the soil texture and porosity necessary for optimum air and water flow in the soil, and release the stored water when the soil is dried up. All of this facilitates the maximum growth potential for plants (Guilherme et al. (2015), Ghobashy (2020)). This is partly due to the fact that leaching of water through gravity in the soil particles is partially suspended by the swollen hydrogel particles in the voids of the soil. It is known that the soil porosity is not affected unless the size of the swollen hydrogel particles or clusters are in the range of centimeters (Chen et al. (2004)). The porosity of soil should not be less than the critical value of 10% for plant growth (Narjary et al. (2012)). However, minimal use of hydrogel is advised for soils with high moisture retaining capacities, as it may hinder plant root aerobic interactions (Parthasarathi et al. (2018)). The presence of hydrogel increases the soil porosity that provides a better oxygenation to the plant roots (Guilherme et al. (2015)).

Field level experiments have been done by Abrisham et al. (2018) by the use of a potassium polyacrylate based hydrogel - stockosorb on S. rosmarinus Bunge ex Boiss. (Amaranthaceae) for the evaluation of effects on properties of sandy loamy soil and plant growth. The study by Abrisham et al. (2018) showed a decrease in infiltration capacity, increase in cation exchange capacity and a decrease in bulk density. In many areas, particularly in Egypt, hydrogels are being experimented upon as a utility to ameliorate the effect of extremely saline soils on plant growth, caused due to irrigation with saline water and poor permeability and drainage, to list a few (Chen et al. (2004), SAYED et al. (1991)). SAYED et al. (1991) indicates a decrease in ionic uptake from saline treatments due to reversal of ionic osmotic exchange between plant-soil-hydrogel chains. Chen et al. (2004) showed that the water content of saline soil amended with hydrogel increased by 41%. Moreover, the saline concentration of the soil was reduced in soils amended with hydrogel.

Hydrogel Impacts on Microbial and Fungal Growth

Microorganisms in the soil matrix play a crucial role in the nutrient pathway for plant uptake. Many bacteria and other single and multicellular species break down the complex nutrients inside the soil and release it to the roots of the plants in its vicinity. A plant root system has a complex interaction with its environment such as rhizobium fauna, fungi, and bacteria. Hence, a healthy population of nitrogen and other nutrient fixing bacteria is tantamount to optimizing the overall yield of the plant (Jacoby et al. (2017)). This ecosystem is important for a sustainable environment for plant growth as this combination in the ecosystem ensures a natural equilibrium between nutrient transfer and survival of each species. As most of these organisms propagate in aqueous situations, the availability of moisture in the form of entrapped water in hydrogels help create incubation tanks for the same.

The interaction of microbes with hydrogel involves complex reactions and exchange of enzymes. The microbes are exposed to nutrient release and degradation products of hydrogel. Since symbiosis is essential for plant growth, hydrogels applied for agricultural productivity should pose no toxicity to the symbiotic organisms. The hydrogels thus require to be tested for any sort of negative effects on microbes.

Cytotoxicity test, and high through-put genome sequencing of soil microbes are popular methods adopted for the evaluation of the effect of hydrogel on microbial communities (Rudzinski et al. (2002), Sannino et al. (2010)). Cytotoxicity test used to measure the extent of damage which the hydrogel, its extract, or its monomers can cause on a living cell and is done using a colorimetric assay based on MTT, a tetrazolium salt (Mosmann (1983)). The test compares the cell viability as a function of concentration compared with Polyethyleneimine (PEI) as control (Kollar et al. (2016)).

A study done by Rudzinski et al. (2002) mentions the use of a genome sequencing method called Illumina MiSeq sequencing, where the genomes of existing microbial communities are measured in soils in the presence of Sodium polyacrylate hydrogel under 4 different conditions of soil moisture. The study by Rudzinski et al. (2002) showed that the diversity of microbes increased with the addition of SAPs and that soil moisture content played a greater role in deciding the degradation of SAPs. Saturated water treatment showed a release of toxic compounds, while severe drought treatment showed a decrease in pH. This discourages the use of PAAm based hydrogels for agricultural purposes. However, polyacrylate-based PUSA hydrogels were used as bioinoculants in a study done by Suman et al. (2016) where the shelf life of microorganisms was boosted from 3 months to 2 years in controlled conditions and the treatment of the select cultures of microbes and hydrogel showed positive effects on plant growth. Although positive effects are observed in the immediate crop production as shown in many studies, the toxicity at longer time periods after degradation requires to be given sufficient scrutiny. Considering the uncertainty projected here, the effects of toxicity of natural polymer-based hydrogels needs to be studied in detail. Starch based hydrogels undergo fermentation, producing sugars, which serve as food for many microbe species. The total microbial count for Actinomycetes, Azotobacter, total fungi, phosphate dissolving bacteria, and Azospirillum progressed when applied to sandy calcareous soil (El-Hady et al. (2011)). Kollar et al. (2016) used MTT assay for AM-SHMB (tulipalin A based) hydrogel, its monomers and extract and found that AM-SHMB doesn't cause toxicity to the cells, or doesn't damage the viability of the cells for 3, 5, and 10 mg/ml of concentrations. Genome sequencing on the other hand is only recently used for agricultural purposes. Another study, by Sannino et al. (2010) showed through MTT assay, that cellulose-based hydrogels have no toxicity towards cell viability. A study by Achtenhagen & Kreuzig (2011) showed that there is an increased microbial activity with the application of hydrogels under deficit conditions. Many

microorganisms contribute majorly to the degradation of the hydrogels themselves, and promote microbial survival. Ghobashy mentions the desirability of aerobic bacteria in soils that fix oxygen to the root systems, and discusses the converse of the anaerobic type, citing their parasitic nature that often leads to competition between the plant and the bacteria themselves for mineral nutrients and nitrogen, leading to diminished plant growth (Ghobashy (2020)).

Hydrogel Impact on Plant Growth

It is important to examine the effect of the altered soil water interactions due to the application of hydrogel on the growth of the plant themselves. A large number of studies have been carried out in this regard in the field of Agronomy. Hence, a sufficient number of results are available to compare the standard methods of cultivation with those that have been augmented with the use of hydrogel, based on a variety of plant growth parameters. The hydrogel is applied to the plants by different methods: either seedlings or seeds are coated with hydrogel, or hydrogel is mixed with the soil adjacent to the sown plants (Kazanskii & Dubrovskii (1992)). The hydrogel binds strongly to the roots of the plants in many cases, and thus enhances the nutrient environment around them. However, the methods can prove counterproductive, as the swollen hydrogel has the chance of blocking soil pores required for aeration resulting in seedling mortality (Ghobashy (2020)). In general, hydrogels have shown to be largely favourable when used to aid cultivation. There are no reported phytotoxicity cases, notably manifested through increased germination indices of many vegetables as well as ornamental species when treated with hydrogels. Trials on cucumber showed an overall increase of over 30cm in plant height, as well as increasing the plant and fruit fresh biomass (by weight) almost twofold (Montesano et al. (2015)). Since the production of chlorophyll is linked to water availability, plants growing in soils without hydrogels have shown significant decrease in chlorophyll content as compared to when hydrogel is applied in soils. Plant defenses against diseases have also been shown to be increased by the action of hydrogel, curbing the actions of a variety of phytopathogens, as well as inhibiting the growth of nutrient intensive fungi species (Ghobashy (2020)). Chen et al. (2004) observed 3.5 times increase in root length and area of tree seedlings when saline (Potassium mine refuse) soils was amended with hydrogels. Since vitality of the plants grown is generally quantitatively measured with respect to certain established independent parameters, this section will try to combine findings from different studies performed on the plants. Plant parameters generally measured as an indicator of its growth potential includes, but are not limited to:

- Water Use Efficiency
- Dry Biomass Weight
- Number of days to Wilting point
- Germination Index
- Root length/surface area
- Shoot length
- Chlorophyll content
- Plant height
- Turgor potential
- Yield weight
- Leaf Water Content

- ***Impact on plant species***

  - ***Maize***

Higher seedling growth for Zea mays cv. 'tri-hybrid 311' in sandy soils in Egypt was observed for higher consequent concentrations of hydrogels added, with 0.4% having the highest growth recorded. Water content of the root and shoots showed an increase of at least 19% and goes to around 50% and even 70%, yielding higher average values for higher concentrations of hydrogel. An increase of fresh weight up to 1.56 to 7.9 times was also observed compared to its respective control (Mazen et al. (2015)).

  - ***Tomato***

Levels of Chlorophyll A and B doubled for Lycopersicon esculentum Mill. species of tomato when Cross-linked Poly (ethylene oxide) co-polyurethane hydrogel was applied to the extremely saline sandy soils they were planted in. This was also accompanied by a consistent increase in photosynthetic activity, measured as a degree of O_2 evolution, in the same trials (SAYED et al. (1991)). Tomatoes (Pomodoro di Morciano di Leuca) were tested over 3 months in the Mediterranean region (province of Italy) with cellulose based SAP in red and white soils. Initially tomatoes were kept in pots and subsequently transferred to large wooden boxes to mimic open field condition. Differing concentrations from 0.2% to a maximum of 1.5% of the SAP was applied to the surface of the soil in each box, and only half the amount of water was supplied to the boxes containing SAP compared to the ones without (120L of water to non-SAP vs 60 L to SAP). The 0.2% hydrogel and control groups bore smaller and wrinkled leaves compared to the rest of the groups with higher SAP concentrations, even with the massive reduction in the amount of water supplied to the latter. The fruit size remained approximately the same (Demitri et al. (2013)).

  - ***Cherry Tomato***

Cellulose based hydrogel with 4 concentrations up to 1% by wt. were mixed into red soil to assess its effect. It was initially observed that the plants reached their wither point when their respective soils reached a water content of 10-20%. Based on this, the control group was shown to take only 4-5 days to reach this stage. An addition of just 0.2% hydrogel increased this to 9 days, while the maximum concentration of 1% increased that further to around 22 days to wither (Demitri et al. (2013)).

  - ***Populus Euphratica***

Plants treated with 0.6% Stockosorb K 410 hydrogel showed a 2.7 times biomass increase over control in saline conditions, over a test period of 2 years. Root length and surface area were also reported to increase 3.5 times (Chen et al. (2004)).

- ***Wheat***

Studies were conducted on wheat (Triticum aestivum L.) irrigation aided with lignite, liquids and hydrogels to assess their microbial and plant growth. Pusa hydrogel used in the experiment reported the highest root and shoot length, as well as the highest fresh and dry weights at 45 and 90 DAS (Suman et al. (2016)). Studies done in sandy calcareous soil from Egypt on the effect on 4 different types of hydrogels also examined its effects on the rhizosphere of the same species of wheat, concluding that it helps increase in growth promoting bacteria, and also boosts enzymatic activity in the plant surrounding. Applications of 2.5g/kg of hydrogel in the soil showed better results for the same as compared to 5g/kg, increasing the phosphate dissolving bacteria, total fungi and actinomycetes count to around 200% that of the control (El-Hady et al. (2011)).

- ***Cucumber***

Researchers showed the ability of a cellulose-based hydrogel to increase the germination indices of radish, cucumber, Alyssum, and Centaurea seeds well above the required 60% (set as a benchmark for signs for phytotoxicity), with cucumber trials reaching upwards of 140%. Pot cultivation trials done of the same showed similar positive results at 35 days after transplant, with 113% increase in plant height, 192% increase in total fresh biomass, 242% increase in fruit biomass, and 162% increase in leaf area. They also expressed higher leaf water potential and turgor potential values when subjected to controlled water stress (Montesano et al. (2015)). In addition, studies done by SAYED et al. (1991) also showed growth of cucumber in extremely saline solution concentration soils of up to 32,000 ppm with the addition of hydrogel, which would be otherwise previously severely impeded in the absence of hydrogel.

- ***Basil***

It has been observed that there was 156% increase in fresh weight at 46 DAS was found for perlite amended with 3% cellulose-based hydrogel as opposed to unadulterated perlite. This number is increased to 177% when 6% hydrogel concentration is used instead. However, this difference becomes less drastic at 63 DAS, showing only a 113% increase in the same parameter (Montesano et al. (2015)).

- ***Brassica Rapa***

0.15% SAP powder used to amend potted soil with fertilizers was shown to give 10% extra yield compared to control over three cycles of sowing and harvest over 30 days. This is significant as no extra hydrogel is added after the first incorporation into the soil, and can potentially use as an indicator of the reusability of the hydrogel itself (Shimomura & Namba (1994)).

- ***Lettuce***

Studies conducted by Woodhouse and Johnson on Lactuca sativa (cv. 'Webb's Wonderful') showed a significant jump in the number of days to wilting point from 2 in control to 15 days for sandy soils amended with PVA hydrogel at the max concentration of 0.5% w/w. Dry weight of lettuce increased six-fold under addition of Polyacrylamide hydrogel from 8 mg per pot to 49 mg per pot of sandy soil. Water use efficiency, another excellent indicator of plant growth efficiency, also had 3-fold growth over its respective control in the experiment (Woodhouse & Johnson (1991)).

- ***Agrostis Stolonifera***

Experiments done on this species of grass in pots with sand from a sand pit in Schoningen, Germany with 0.4% Luquasorb hydrogel showed an increase in the root and shoot biomass measurements by 4 and 2.2 times, respectively. The water use efficiency also was observed increased by 8 times from 1.56g/L to 13.7g/L. The total amount of water used was also lessened by 3 times from 24L in control to 8.4L in 0.4% hydrogel concentration (Agaba et al. (2011)).

- ***Faba bean***

The effect of irradiated polyacrylamide and PAAm/Na-alginate copolymer hydrogel was assessed with the help of the growth of faba bean (Vicia faba L. Family: Leguminosae) in semi-potted sandy soil in Egypt and showed clear higher biomass and plant height measurements at 9 weeks after sowing (Abd El-Rehim (2006)).

Hydrogel Degradability

Non degradability of most synthetic hydrogels can pose environmental threat. The problem of degradation arose with extensive application of hydrogel polymers in the medical industry. Two ways for the degradation of synthetic polymers were identified - introduction of functional groups in the crosslinks of hydrogel that can undergo hydrolysis; and exposure of hydrogels to enzymes that can break the polymer backbone of the hydrogel matrix (Meyvis et al. (2000)). Research had been conducted to evaluate the effect of degradation on the swelling of hydrogel. The swelling is affected by the mechanism of degradation. In the former case where the crosslinks are degraded, the density of crosslinks in the matrix reduces resulting in an increased swelling until a stage where the hydrogel becomes unstable. In the latter case of enzymatic degradation of polymer backbone, the crosslinks remain with no loss of crosslinking density in the hydrogel matrix, resulting with no changes in swelling until it drops after the matrix destabilizes (Meyvis et al. (2000)). In view of application in agricultural lands, as seen in section 4.2, the hydrogels in soil serve as sources of carbon and medium for locomotion for microbes in the soil. The microbes feed on the substances that the hydrogel is made of as well as the compounds released after the collapse or degradation of the hydrogel matrix. Thus, biodegradation is a possible option and arguably the most coveted degradation mechanism for hydrogels. Chitosan was the first explored material with respect to biodegradability in hydrogels since it had better mimic of cell behavior. Chitosan is N-deacetylated chitin which is found in various bacteria, fungi, and crustaceans

(Qureshi & Khatoon (2015)). Qureshi & Khatoon (2015) conducted a 12-week open environment degradability test of chitosan-based hydrogel with soil. It proved the biodegradability of the same.

Biodegradability is a sought-out property for hydrogel to be applied in agriculture and could be a sustainable mechanism. Several studies have been done to assess variety of hydrogels for biodegradability. Natural polymer-based hydrogels degrade easily in soil, while synthetic polymers take very long to degrade as detailed in section 2.1 (Jamnongkan & Kaewpirom (2010)). Over the past few decades, the preparation of super absorbents has been primarily based on synthetic polymers such as acrylic acid (AA) or acrylamide (AM), which could be potential environment hazards due to their poor biodegradability (about 10% per year) (Cannazza et al. (2014), Zhang et al. (2014)).

In section 4.2, the products of pyrolysis of polyacrylate based hydrogels have been mentioned. The compounds of degradation from biodegradation as well as pyrolysis were similar with varying fractions of hydrocarbons and fatty acids. Some products of pyrolysis were unique such as long chain amides, esters, silanes, and sulfonyl groups (Rudzinski et al. (2002)) which pose toxicity to the biota and environment. It is argued that while polyacrylates are nontoxic, only the monomer acrylamide is toxic. The degradation products of this polyacrylate cellulose based hydrogel are said to be carbon dioxide and amines only and could be identified by use of carbon 13 isotopes (Wilske et al. (2014)). The C=O group was labelled with carbon 13 isotope for every 5 crosslinks. The amount of carbon 13 detected in the carbon dioxide emitted from the soil hydrogel sample at regular intervals showed that the overall degradation was less than 1% in 6 months (Wilske et al. (2014)). A study done by Stahl et al. (2000) explored the biodegradability of polyacrylate and polyacrylamide copolymer with white rot fungus in soil along with soil microbiome. The study showed that the microbial degradation was very low when compared to fungal or fungus-microbe coupled degradation. However, degradation was sufficient to validate. In an open environment degradation study, it was unequivocally presented that the degradation of the polymer-based hydrogel occurred due to microbial action.

Studies also verified the change in swelling properties of the hydrogel over a period of time. Fourier transform infrared spectroscopy, differential scanning calorimetry, thermogravimetric analysis, x-ray diffraction, and field emission scanning electron microscopy were conducted to gain insight into the microscopic structural changes (Qureshi & Khatoon (2015), Meyvis et al. (2000)). These provide data on the development of structural characteristics, which can be reviewed to examine the deterioration of the gel backbone. Porosity, shape and surface variations were reviewed using scanning electron microscope in the studies. Freezing and drying process was used to preserve the morphology of the Gel section (Montesano et al. (2015)). Small depositions were detected, which were construed as microorganisms after decomposition of the substrate. It was observed that the hydrogel using nutrients for microbial growth had helped in rapid decomposition (Qureshi & Khatoon (2015)).

Several commercially available hydrogels are based on polyacrylates with few alterations to the polymer backbone with cellulose (Kalhapure et al. (2016)). The insufficiency and contradicting results arise from studies done from different approaches. There is a need for establishing an integrated approach towards testing degradability by microbes, and identification of residual degradation compounds from pyrolysis and microbial degradation. The integration would help in determination of short term and long-term toxicity or nontoxicity of hydrogels. This problem could be eliminated by a shift towards using natural polymers completely replacing synthetic polymers which require special enzymes for effective decomposition. It could be favourable for sustainable agriculture practices.

The degradation products and the monomers extracted from AM-SHMB (tulipalin-A based hydrogel) showed no cytotoxicity on fibroblast cells (Kollar et al. (2016)). Cellulose based hydrogel degrades easier in sandy soils under the action of soil microbiome enhanced with nutrient release (Nie et al. (2004)). A study done by Ekebafe et al. (2011) investigated the process of degradation of gum tragacanth-acrylic acid-based hydrogel by soil microbiome and observed a 92% degradation in 10 weeks. The study found that the degradation products enhanced the carbon content, phosphorus and potassium contents of the soil which promotes plant growth. A slight decrease in pH of about 1.5% (within limits) was observed. A similar study by Saruchi et al. (2016) showed significant increase in plant nutrients availability in soil with a 3% increase in pH. The variability is a result of soil properties and existing conditions. Since the variability is within limits, it can be neglected. The breaking down of several polymers into respective monomers with the release of nutrients in the soil increases nutrient efficiency and availability of the soil.

Conclusion

Agricultural sustainability is essential to enhance food and water security, particularly in the context of climate change. In the recent past application of hydrogels in agriculture have received substantial attention among researchers as well as among farmers. Like its medical applications, a wider scope for hydrogels has been identified in agriculture. Hydrogel could be envisaged as an effective soil conditioner in arid and semi-arid regions. It would enhance soil texture; provide the required porosity for optimum flow of air and water; mitigates the effect of soil salinity on plants; and release of stored water in dried soil. As the typology of materials is of importance for research and development, the study makes an attempt to present various hydrogel classifications. Ideal properties to be considered for synthesis of hydrogel agricultural application have been identified. There exists a tradeoff between natural and synthetic polymers for their degradability and durability. Comparative studies on the growth of plants have been proven to be extremely valuable. Hydrogels are good soil conditioners which can improve water use efficiency, plant health and yield, and can reduce irrigation water requirements. Hence hydrogel application would be

beneficial for crops such as paddy and wheat which have large water footprints.

Further studies could definitely be conducted on developing hydrogels which can mitigate the effect of saline soils on the crop growth. Novel stimuli-responsive hydrogels with release mechanisms based on moisture and time, for efficient use of fertilizers, pesticides, and fungicides. Natural polymer-based hydrogels should be studied in detail in view of improving biodegradability and water retention capacity. Such an understanding would help nations such as India for increasing the irrigation efficiency and soil conditioning for sustainable agricultural production. Further studies on the laboratory test methods on the hydrogel durability is found to be necessary to make it affordable for the farming communities and for its cost-effectiveness while scaling up to the farm level. Discussions on hydrogel properties and degradation show that there is a need to develop an integrated framework for test methods of various properties, for effective comparison of results for agricultural use. With adequate further studies we foresee the popularity of hydrogels among the farming communities for various crops. Integrating innovative solutions with environmentally-friendly hydrogels in the coming decade will contribute to the pursuit of achieving sustainable development goals.

References

2720, I. (1983), 'Methods of test for soils–determination of density index for cohesionless soils'.

Abd El-Rehim, H. A. (2006), 'Characterization and possible agricultural application of polyacrylamide/sodium alginate crosslinked hydrogels prepared by ionizing radiation', *Journal of Applied Polymer Science* 101(6), 3572–3580.

Abrisham, E. S., Jafari, M., Tavili, A., Rabii, A., Zare Chahoki, M. A., Zare, S., Egan, T., Yazdanshenas, H., Ghasemian, D. & Tahmoures, M. (2018), 'Effects of a super absorbent polymer on soil properties and plant growth for use in land reclamation', *Arid Land Research and Management* 32(4), 407–420.

Achtenhagen, J. & Kreuzig, R. (2011), 'Laboratory tests on the impact of superabsorbent polymers on transformation and sorption of xenobiotics in soil taking 14c-imazalil as an example', *Science of the total environment* 409(24), 5454–5458.

Agaba, H., Orikiriza, L. J., Obua, J., Kabasa, J. D., Worbes, M., Hüttermann, A. et al. (2011), 'Hydrogel amendment to sandy soil reduces irrigation frequency and improves the biomass of agrostis stolonifera', *Agricultural Sciences* 2(04), 544.

Ahmadi, F., Oveisi, Z., Samani, S. M. & Amoozgar, Z. (2015), 'Chitosan based hydrogels: characteristics and pharmaceutical applications', *Research in pharmaceutical sciences* 10(1), 1.

Ahmed, E. M. (2015), 'Hydrogel: Preparation, characterization, and applications: A review', *Journal of advanced research* 6(2), 105–121.

Allen, M., Dube, O., Solecki, W., Aragón-Durand, F., Cramer, W., Humphreys, S., Kainuma, M., Kala, J., Mahowald, N., Mulugetta, Y. et al. (2018), 'Framing and context', *Global warming of* 1, 49–91.

Bhattacharya, A. (2018), *Changing Climate and Resource Use Efficiency in Plants*, Academic Press.

Brazel, C. S. & Peppas, N. A. (1999), 'Mechanisms of solute and drug transport in relaxing, swellable, hydrophilic glassy polymers', *Polymer* 40(12), 3383–3398.

Bruck, S. D. (1973), 'Aspects of three types of hydrogels for biomedical applications', *Journal of Biomedical Materials Research* 7(5), 387–404.

Cannazza, G., Cataldo, A., De Benedetto, E., Demitri, C., Madaghiele, M. & Sannino, A. (2014), 'Experimental assessment of the use of a novel superabsorbent polymer (sap) for the optimization of water consumption in agricultural irrigation process', *Water* 6(7), 2056–2069.

Chen, J., Park, H. & Park, K. (1999), 'Synthesis of superporous hydrogels: Hydrogels with fast swelling and superabsorbent properties', *Journal of Biomedical Materials Research: An Official Journal of The Society for Biomaterials, The Japanese Society for Biomaterials, and the Australian Society for Biomaterials* 44(1), 53–62.

Chen, S., Zommorodi, M., Fritz, E., Wang, S. & Hüttermann, A. (2004), 'Hydrogel modified uptake of salt ions and calcium in populus euphratica under saline conditions', *Trees* 18(2), 175–183.

De Boodt, M. (1975), 'Use of soil conditioners around the world', *Soil Conditioners* 7, 1–12.

Demitri, C., Scalera, F., Madaghiele, M., Sannino, A. & Maffezzoli, A. (2013), 'Potential of cellulose-based superabsorbent hydrogels as water reservoir in agriculture', *International Journal of Polymer Science*.

Devineni, N., Perveen, S. & Lall, U. (2013), 'Assessing chronic and climate-induced water risk through spatially distributed cumulative deficit measures: A new picture of water sustainability in india', *Water Resources Research* 49(4), 2135–2145.

ECOSOC, U. (2019), 'Special edition: Progress towards the sustainable development goals report of the secretary-general', *Advanced unedited version. New York (US): United Nations*.

Ekebafe, L., Ogbeifun, D. & Okieimen, F. (2011), 'Polymer applications in agriculture', *Biokemistri*.

El-Hady, O., Abo-Sedera, S., Basta, A. & El-Saied, H. (2011), 'The role of rice straw-based hydrogels on some soil microorganisms' strains', *Bio* 1, 78–84.

Frantz, J. M., Locke, J. C., Pitchay, D. S. & Krause, C. R. (2005), 'Actual performance versus theoretical advantages of polyacrylamide hydrogel throughout bedding plant production', *Hort Science* 40(7), 2040–2046.

Fumio, U., Hiroshi, Y., Kumiko, N., Sachihiko, N., Kenji, S. & Yasunori, M. (1990), 'Swelling and mechanical properties of poly (vinyl alcohol) hydrogels', *International journal of pharmaceutics* 58(2), 135–142.

Ghobashy, M. M. (2020), The application of natural polymer-based hydrogels for agriculture, *in* 'Hydrogels Based on Natural Polymers', Elsevier, pp. 329–356.

Guilherme, M. R., Aouada, F. A., Fajardo, A. R., Martins, A. F., Paulino, A. T., Davi, M. F., Rubira, A. F. & Muniz, E. C. (2015), 'Superabsorbent hydrogels based on polysaccharides for application in agriculture as soil

conditioner and nutrient carrier: A review', *European Polymer Journal* 72, 365–385.

Ines, A. V., Honda, K., Gupta, A. D., Droogers, P. & Clemente, R. S. (2006), 'Combining remote sensing-simulation modeling and genetic algorithm optimization to explore water management options in irrigated agriculture', *agricultural water management* 83(3), 221– 232.

Ismail, H., Irani, M. & Ahmad, Z. (2013), 'Starch-based hydrogels: present status and applications', *International Journal of Polymeric Materials and Polymeric Biomaterials* 62(7), 411–420.

Jacoby, R., Peukert, M., Succurro, A., Koprivova, A. & Kopriva, S. (2017), 'The role of soil microorganisms in plant mineral nutrition—current knowledge and future directions', *Frontiers in plant science* 8, 1617.

Jamnongkan, T. & Kaewpirom, S. (2010), 'Potassium release kinetics and water retention of controlled-release fertilizers based on chitosan hydrogels', *Journal of Polymers and the Environment* 18(3), 413–421.

Jha, A. K., Malla, R., Sharma, M., Panthi, J., Lakhankar, T., Krakauer, N. Y., Pradhanang, S. M., Dahal, P. & Shrestha, M. L. (2016), 'Impact of irrigation method on water use efficiency and productivity of fodder crops in nepal', *Climate* 4(1), 4.

Kalhapure, A., Kumar, R., Singh, V. P. & Pandey, D. (2016), 'Hydrogels: a boon for increasing agricultural productivity in water-stressed environment', *Current Science* pp. 1773–1779.

Katayama, T., Nakauma, M., Todoriki, S., Phillips, G. O. & Tada, M. (2006), 'Radiation- induced polymerization of gum arabic (acacia senegal) in aqueous solution', *Food hydrocolloids* 20(7), 983–989.

Kazanskii, K. & Dubrovskii, S. (1992), Chemistry and physics of "agricultural" hydrogels *in* 'Polyelectrolytes hydrogels chromatographic materials', Springer, pp. 97–133.

Kollar, J., Mrlik, M., Moravcikova, D., Kronekova, Z., Liptaj, T., Lacik, I. & Mosnacek, J. (2016), 'Tulips: a renewable source of monomer for superabsorbent hydrogels', *Macromolecules* 49(11), 4047–4056.

Körner, A., Piculell, L., Iselau, F., Wittgren, B. & Larsson, A. (2009), 'Influence of different polymer types on the overall release mechanism in hydrophilic matrix tablets', *Molecules* 14(8), 2699–2716.

Latif, I. A., Abdullah, H. M. & Saleem, M. H. (2016), 'Electrical and swelling study of different prepared hydrogel', *Am J Polym Sci* 6(2), 50–57.

Lelieveld, J., Hadjinicolaou, P., Kostopoulou, E., Chenoweth, J., El Maayar, M., Giannakopoulos, C., Hannides, C., Lange, M., Tanarhte, M., Tyrlis, E. et al. (2012), 'Climate change and impacts in the eastern mediterranean and the middle east', *Climatic change* 114(3-4), 667–687.

Mazen, A. M., Radwan, D. E. M. & Ahmed, A. F. (2015), 'Growth responses of maize plants cultivated in sandy soil amended by different superabsorbant hydrogels', *Journal of Plant Nutrition* 38(3), 325–337.

Meyvis, T., De Smedt, S., Demeester, J. & Hennink, W. (2000), 'Influence of the degradation mechanism of hydrogels on their elastic and swelling properties during degradation', *Macromolecules* 33(13), 4717–4725.

Montesano, F. F., Parente, A., Santamaria, P., Sannino, A. & Serio, F. (2015), 'Biodegradable superabsorbent hydrogel increases water retention properties of growing media and plant growth', *Agriculture and Agricultural Science Procedia* 4, 451–458.

Mosmann, T. (1983), 'Rapid colorimetric assay for cellular growth and survival: application to proliferation and cytotoxicity assays', *Journal of immunological methods* 65(1-2), 55– 63.

Murphy, S. M., Skelly, P. J. & Tighe, B. J. (1992), 'Synthetic hydrogels. part 9—preparation and characterisation of macroporous hydrophilic matrices', *Journal of Materials Chemistry* 2(10), 1007–1013.

Narjary, B., Aggarwal, P., Singh, A., Chakraborty, D. & Singh, R. (2012), 'Water availability in different soils in relation to hydrogel application', *Geoderma* 187, 94–101.

Neethu, T., Dubey, P. & Kaswala, A. (2018), 'Prospects and applications of hydrogel technology in agriculture', *Int. J. Curr. Microbiol. App. Sci* 7(5), 3155–3162.

Nie, H., Liu, M., Zhan, F. & Guo, M. (2004), 'Factors on the preparation of carboxymethylcellulose hydrogel and its degradation behavior in soil', *Carbohydrate Polymers* 58(2), 185–189.

Omidian, H., Rocca, J. G. & Park, K. (2005), 'Advances in superporous hydrogels', *Journal of controlled release* 102(1), 3–12.

Parthasarathi, T., Vanitha, K., Mohandass, S. & Vered, E. (2018), 'Evaluation of drip irrigation system for water productivity and yield of rice', *Agronomy Journal* 110(6), 2378–2389.

Paul, A., Laurila, T., Vuorinen, V. & Divinski, S. V. (2014), *Thermodynamics, diffusion and the Kirkendall effect in solids*, Springer.

Piao, S., Ciais, P., Huang, Y., Shen, Z., Peng, S., Li, J., Zhou, L., Liu, H., Ma, Y., Ding, Y. et al. (2010), 'The impacts of climate change on water resources and agriculture in china', *Nature* 467(7311), 43–51.

Pritchard, R. H. & Terentjev, E. M. (2013), 'Swelling and de-swelling of gels under external elastic deformation', *Polymer* 54(26), 6954–6960.

Qureshi, M. A. & Khatoon, F. (2015), 'Open environment degradability study of cs/pvp/pnipam hydrogel film', *Journal of Applicable Chemistry* 4(3), 903–908.

Rehman, A., Ahmad, R. & Safdar, M. (2011), 'Effect of hydrogel on the performance of aerobic rice sown under different techniques', *Plant, Soil and Environment* 57(7), 321– 325.

Rosenstock, T. S., Nowak, A. & Girvetz, E. (2018), *The Climate-Smart Agriculture Papers: Investigating the Business of a Productive, Resilient and Low Emission Future*, Springer.

Roy, T., Kumar, S., Chand, L., Kadam, D., Bihari, B., Shrimali, S., Bishnoi, R., Maurya, U., Singh, M., Muruganandam, M. et al. (2019), 'Impact of pusa hydrogel application on yield and productivity of rainfed wheat in north west himalayan region.', *Current Science (00113891)*.

Rudzinski, W. E., Dave, A. M., Vaishnav, U. H., Kumbar, S. G., Kulkarni, A. R. & Aminabhavi, T. (2002), 'Hydrogels as

controlled release devices in agriculture', *Designed monomers and polymers* 5(1), 39–65.

Rychter, P., Rogacz, D., Lewicka, K., Kollár, J., Kawalec, M. & Mosnáčˇek, J. (2019), 'Ecotoxicological properties of tulipalin a-based superabsorbents versus conventional superabsorbent hydrogels', *Advances in Polymer Technology*.

Sannino, A., Madaghiele, M., Demitri, C., Scalera, F., Esposito, A., Esposito, V. & Maffezzoli, A. (2010), 'Development and characterization of cellulose-based hydrogels for use as dietary bulking agents', *Journal of applied polymer science* 115(3), 1438–1444.

Sarkar, S., Basu, B., Kundu, C. & Patra, P. (2012), 'Deficit irrigation: An option to mitigate arsenic load of rice grain in west bengal, india', *Agriculture, ecosystems & environment* 146(1), 147–152.

Saruchi, B., Kumar, V. & Jindal, R. (2016), 'Biodegradation study of enzymatically catalyzed interpenetrating polymer network: Evaluation of agrochemical release and impact on soil fertility', *Biotechnology Reports* 9, 74.

SAYED, H. E., Kirkwood, R. & Graham, N. (1991), 'The effects of a hydrogel polymer on the growth of certain horticultural crops under saline conditions', *Journal of Experimental Botany* 42(7), 891–899.

Shimomura, T. & Namba, T. (1994), Preparation and application of high-performance superabsorbent polymers, ACS Publications.

Shin, J., Braun, P. V. & Lee, W. (2010), 'Fast response photonic crystal ph sensor based on templated photo-polymerized hydrogel inverse opal', *Sensors and Actuators B: Chemical* 150(1), 183–190.

Smith, B. D. & Zeder, M. A. (2013), 'The onset of the anthropocene', *Anthropocene* 4, 8–13.

Stahl, J. D., Cameron, M. D., Haselbach, J. & Aust, S. D. (2000), 'Biodegradation of superabsorbent polymers in soil', *Environmental Science and Pollution Research* 7(2), 83– 88.

Stuart, M. A. C., Huck, W. T., Genzer, J., Müller, M., Ober, C., Stamm, M., Sukhorukov, G. B., Szleifer, I., Tsukruk, V. V., Urban, M. et al. (2010), 'Emerging applications of stimuli-responsive polymer materials', *Nature materials* 9(2), 101–113.

Suman, A., Verma, P., Yadav, A. N., Srinivasamurthy, R., Singh, A. & Prasanna, R. (2016), 'Development of hydrogel-based bio-inoculant formulations and their impact on plant biometric parameters of wheat (triticum aestivum l.)', *Int J Curr Microbiol Appl Sci* 5(3), 890–901.

Tayel, M. & El-Hady, O. (1981), Super gel as a soil conditioner 1-its effect on some soil- water relations, *in* 'III International Symposium on Water supply and Irrigation in the open and under Protected Cultivation 119', pp. 247–256.

Tellis, J. C., Strulson, C. A., Myers, M. M. & Kneas, K. A. (2011), 'Relative humidity sensors based on an environment-sensitive fluorophore in hydrogel films', *Analytical chemistry* 83(3), 928–932.

Tokarev, I., Gopishetty, V., Zhou, J., Pita, M., Motornov, M., Katz, E. & Minko, S. (2009), 'Stimuli-responsive hydrogel membranes coupled with biocatalytic processes', *ACS applied materials & interfaces* 1(3), 532–536.

Wallace, A. (1986), 'A polysaccharide (guar) as a soil conditioner', *Soil science* 141(5), 371 373.

Wilske, B., Bai, M., Lindenstruth, B., Bach, M., Rezaie, Z., Frede, H.-G. & Breuer, L. (2014), 'Biodegradability of a polyacrylate superabsorbent in agricultural soil', *Environmental Science and Pollution Research* 21(16), 9453–9460.

Woodhouse, J. & Johnson, M. (1991), 'Effect of superabsorbent polymers on survival and growth of crop seedlings', *Agricultural water management* 20(1), 63–70.

Xiao, X., Yu, L., Xie, F., Bao, X., Liu, H., Ji, Z. & Chen, L. (2017), 'One-step method to prepare starch-based superabsorbent polymer for slow release of fertilizer', *Chemical Engineering Journal* 309, 607–616.

Zhang, Y., Liang, X., Yang, X., Liu, H. & Yao, J. (2014), 'An eco-friendly slow-release urea fertilizer based on waste mulberry branches for potential agriculture and horticulture applications', *ACS Sustainable Chemistry & Engineering* 2(7), 1871–1878.

Journal of Experimental Biology and Agricultural Sciences, December - 2021; Volume – 9(6) page 727 – 733

Journal of Experimental Biology and Agricultural Sciences

http://www.jebas.org

ISSN No. 2320 – 8694

DROUGHT MITIGATION THROUGH HYDROGEL APPLICATION IN RICE (*Oryza sativa* L.) CULTIVATION

Boreddy Surya Prakash Reddy[1,*], Sriram Vasudevan[1], Shibu K Mani[1], Sirisha Uppaluri[1], M Sudakar[2]

[1]Department of Civil Engineering, CHRIST (Deemed to be University), School of Engineering and Technology, Bengaluru 560074, India
[2]Department of Agronomy, Pendekanti Krishi Vigyan Kendra, Kurnool 518124, India

Received – September 13, 2021; Revision – November 23, 2021; Accepted – December 12, 2021
Available Online – December 30, 2021

DOI: http://dx.doi.org/10.18006/2021.9(6).727.733

KEYWORDS

Drought

Mitigation

Hydrogel

Sustainability

Agriculture

Rice

Soil conditioning

ABSTRACT

Sustainability in irrigation is an essential step towards responsible water consumption. In recent years, many studies have sketched climate-resilient agricultural practices to fight drought and uncertain rainfall patterns. Major rain-fed crops such as paddy and wheat require aid when there are abnormal dry spells. To mitigate the loss of crops from such events, superabsorbent polymers can be used. Soils amended with hydrogel or Superabsorbent polymer (SAP) retain moisture during drought to prevent loss of water through evaporation and percolation. This allows the crop to grow with less shock from drought. This study compares rice (*Oryza sativa* L.) growth rate under application (treatment groups) and non-application (control groups) of hydrogel, considering their high-water requirement. NDLR07 (recently developed) and BPT5204 (local variety) rice varieties were chosen for the current study. Randomized controlled trials were performed for each variety on a control group (NC & BC) and 3 treatment groups with 20% (NT20 & BT20), 40% (NT40 & BT40), and 60% (NT60 & BT60) deficit water supplies respectively. N, T, C refers to seed type, treatment group, control group respectively. Intermittent drought condition was imposed for 14 days to assess the resilience of crops. The water retention capacity of the sandy loam soil was better for treatment groups by 20% than control groups even at an average temperature of 40 °C. Treatment groups continued growing through the drought phase and after, while control groups showed stagnation. Among the tested treatment groups, NT20 had the highest growth among all trials. The results of the study suggested that hydrogel application can help to combat droughts and thereby contribute to sustainable agricultural production by restricting the involvement of climate changes.

* Corresponding author
E-mail: boreddyspr1@gmail.com (Boreddy Surya Prakash Reddy)

Peer review under responsibility of Journal of Experimental Biology and Agricultural Sciences.

Production and Hosting by Horizon Publisher India [HPI] (http://www.horizonpublisherindia.in/).
All rights reserved.

All the articles published by Journal of Experimental Biology and Agricultural Sciences are licensed under a Creative Commons Attribution-NonCommercial 4.0 International License Based on a work at www.jebas.org.

1 Introduction

Climate change might shift the paradigms of living conditions on earth in the next hundred years (IPCC, 2019). The frequency of droughts due to climate change is expected to increase in the coming decades, which adversely affects the growth of major food crops. In this scenario, sustainability towards food security should be ensured by checking the water consumption of high-water consuming crops concerning climate change. Rice (*O. sativa*) is a crop that consumes a high amount of water and is a staple diet globally that demands attention (Chun et al., 2016). Various strategies such as aerobic cultivation of rice (Rehman et al., 2011), subsurface drip irrigation (Parthasarathy et al., 2018), deficit irrigation (Pirmoradian et al., 2004), water management techniques, use of tension-meter (Kalyanasundaram et al., 2021), use of drought resistance cultivar, and nutrient management have been successfully put forward to mitigate the adverse effects of droughts on agricultural productivity. The application of soil conditioners is one of the methods which enables the soil to retain moisture for extended periods (Kalhapure et al., 2016, Neethu et al., 2018).

Superabsorbent polymers (SAPs) or hydrogels can be used as soil conditioners to amend sandy soils to prevent accelerated evaporation and leaching of nutrients and water beyond the root zone of plants. Hydrogels are composed of hydrophilic homopolymer (*N*-iso-propyl methacrylamide) or copolymer networks and can swell in water or physiological fluids. Chemical cross-links (covalent bonds) or physical junctions (e.g., secondary forces, crystallite formation, chain entanglements) provide the hydrogels' unique swelling behavior in a three-dimensional structure (Ahmed, 2015). The swelling enables hydrogel to act as a water reservoir for plants in the root zone for uptake during water stress. The agricultural application of hydrogels has been extensively studied by Guilherme et al. (2015). Further, Rehman et al., (2011), studied its application on rice and reported 18 % higher growth in soil treated with hydrogel than ordinary soil conditions. In another study, Prakash et al. (2021), suggested that a up to 60 % deficit water supply could give better crop growth for the initial stages under hydrogel application. Similarly, Sen et al. (2019), showed that hydrogel allowed sustained paddy crop growth under drought conditions. This paper aims to present the crop growth pattern of rice under the influence of hydrogel with a deficit supply of water and induced drought conditions to ascertain the extent of reduction of water consumption of paddy.

2 Materials and Methods

2.1 Seed variety

For this study, seeds of 2 rice varieties viz., BPT5204 and NDLR07 were selected. BPT5204 is the locally used variety, while NDLR07 was the recently developed drought-resistant rice variety (Jayalakshmi et al., 2020). NDLR07 showed a greater yield and economic benefit when compared with BPT5204. The study on seed growth, as influenced by hydrogel, would give a greater clarity towards climactic action in agricultural practices.

2.2 Field conditions

The present study was conducted at the experimental station of Krishi Vigyan Kendra (an integral part of the National Agricultural Research System in India), Banaganapalli, Andhra Pradesh (Figure 1). The experiments were conducted during the rabi season (Feb-April 2021) under sandy loam soil (75% sand, 12% silt, and 13%

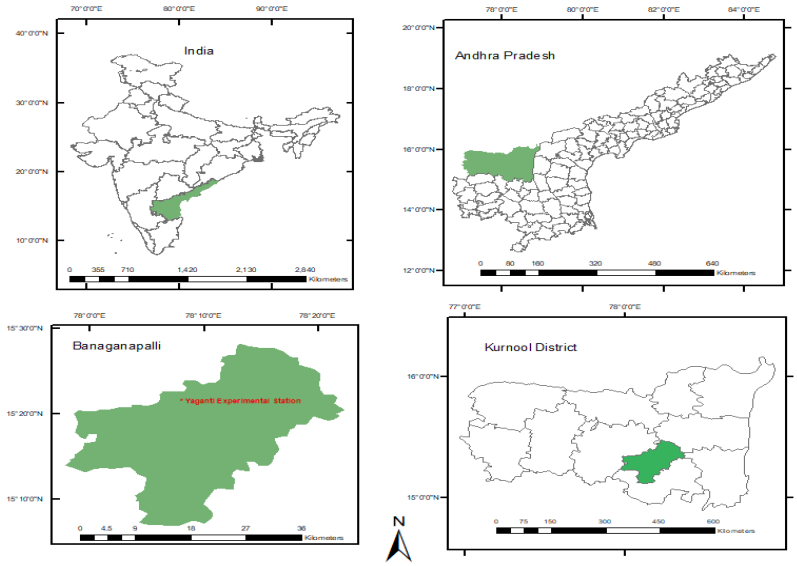


Figure 1 Location of Yaganti field experimental station of Krishi Vigyan Kendra.

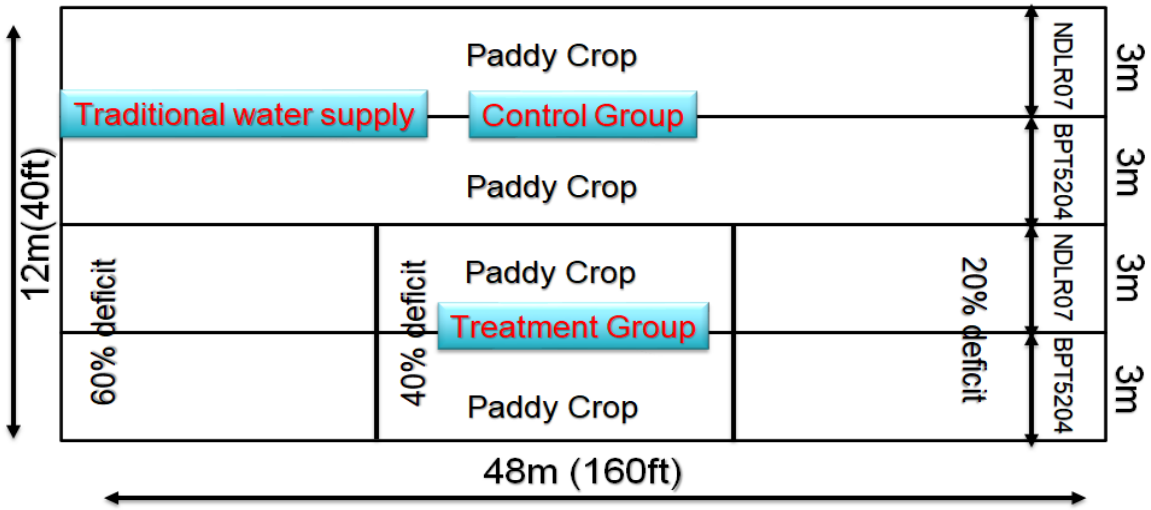


Figure 2 Layout of experimental groups for comparative study in the field for NDLR07 and BPT5204. Based on water supply, the crops were grouped as BC (BPT5204 control) and NC (NDLR07 control); while BT20, BT40, BT60 were used for BPT5204 treatment groups; and NT20, NT40, NT60 used for NDLR07 treatment groups with 20%, 40%, and 60% deficit water supply respectively for each variety.

clay). Randomized controlled trials with Control and treatment groups were laid out as shown in Figure 2. The total net plot size of the experimental setup is 576 sq. m. Treatment groups were grown in soil amended with hydrogel and 3 different water supply deficits as done in a previous study (Prakash et al., 2021). The control group was supplied with 1 cm of water for 28 days after sowing (DAS); 2.2 cm of water from 28-45 DAS; and 0.5 cm of water till the maturation crop. The treatment groups were supplied at varying intervals to meet the deficit conditions.

Irrigation was withheld for two weeks in the absence of rain to induce a drought condition so that the tolerance of crops to water stress could be observed and compared for correlation with hydrogel application. A drought situation was created between the 100 DAS and 114 DAS (Days after sowing). Harvesting was carried out manually in the second week of June 2021, when panicles were fully ripened.

2.3 Sowing techniques and hydrogel application

The method of direct sowing (Sudharani et al., 2019) was adopted in the study and a drum seeder was used for seeding. These drum seeders (Figure 3) consisted of four plastic seed drums mounted on a shaft, ground wheels, floats, and a handle. The seed drum was cylindrical and had a diameter of 200 mm. There were nine seed metering holes (funnel-shaped) of 8 mm diameter along the circumference of the drum at both ends, with a row to row spacing of 200 mm. The direct seeding technique was adopted to reduce transplantation costs and eliminate the high initial water demand for transplanted rice.

Figure 3 (Left) Drum seeder used in the experiment. (Right) Crop height measurement and examination

The hydrogel was applied manually at the time of soil preparation at 2.5 kg/ha as per ICAR recommendations (Lather et al., 2015; Kalhapure et al., 2016). Sprouted paddy seeds were sown using the drum seeder. A fertilizer dose of 133–85–62 kg NPK/ha was applied. Weed Management was done through a cono-weeder (Sudharani et al., 2019), and it was run in the direction in which the drum-seeder was pulled. All other agronomic practices were kept normal and uniform for all the treatments. The treatment group received a 40% deficit supply of all the supplies to the crop compared to the control group.

2.4 Statistical Analysis

Collected data were statistically analyzed using one-way analysis of variance (ANOVA) in SAS software.

3 Results

The plant growth trend in terms of height is presented in Figure 4 (A and B). In both varieties of rice (BPT5204 and NDLR07), a clear difference in plant height is seen between the experimental groups. The differences in the growth rate of each treatment group in the growth period are represented in fig. 4A and 4B.

The best-fit curves of the 3rd degree showed the highest correlation. The equations of plant height for BPT5204 as a function of the number of days are as follows:

$$PB20 = -7.728 \times 10^{-5}(X^3) + 0.01306(X^2) + 0.4031(X) - 1.185, \quad (1)$$

$$PB40 = -7.375 \times 10^{-5}(X^3) + 0.01325(X^2) + 0.2294(X) + 0.8474, \quad (2)$$

$$PB60 = -4.996 \times 10^{-5}(X^3) + 0.00925(X^2) + 0.3566(X) - 0.6088, \quad (3)$$

$$PBC = -8.312 \times 10^{-5}(X^3) + 0.0144(X^2) + 0.2595(X) + 0.2856, \quad (4)$$

Where PB20, PB40, PB60, and PBC are the plant heights of BT20, BT40, BT60, and BC groups respectively; X is DAS. The R^2 values were 0.9971, 0.9971, 0.9939, and 0.9979; the RMSE values were 2.0015, 2.6064, 2.4618, and 1.6032, respectively for eq.1, 2, 3, and 4.

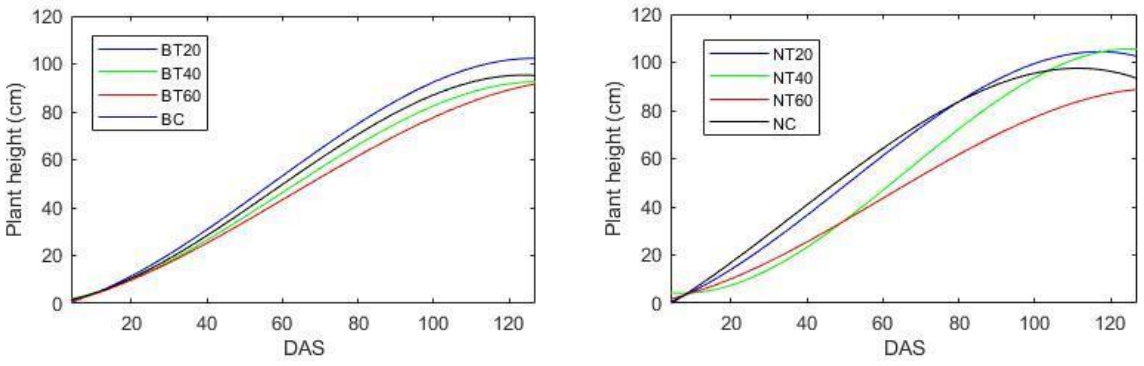
In BPT5204 (Figure 4A), at the end of the harvest period, the treatment group with a 20% deficit supply of water had the highest growth. Compared to the control group, the growth of BT20 was higher by 9%, BT40 lesser by 1%, and BT60 lesser by 3% at the end of the harvest period. From Figure 4 (A), BT40 and BC show a similar growth trend with comparable plant height values. Throughout the cultivation period, the growth percentage gradually reduced for all experimental groups. Figure 5(A) shows that BT60 exhibited the lowest and highest growth rates among all groups. The growth rate varies in a wavy pattern, with peaks and troughs. BT20 exhibited 4 peak rates at an interval of 24-32 days with the highest peak at 48 DAS. BT40 showed 5 peaks at intervals of 16-32 days with the highest at 48 DAS. BT60 showed 4 peaks at intervals of 16-24 days with the highest at 72 DAS. BC showed 3 peaks at intervals of 16-24 days and a gradual decrease in growth rate after the 3rd peak. During the induced drought period from 100 DAS to 113 DAS, the treatment groups showed no significant decrease in growth rates as seen in the control group.

In NDLR07, NT20 showed the highest plant height at the end of the harvest period (105.2 cm). The best fit 3rd degree equations for the plant height of NDLR07 variety are given below:

$$PN20 = -9.198 \times 10^{-5}(X^3) + 0.01378(X^2) + 0.5554(X) - 1.185, \quad (5)$$

$$PN40 = -1.237 \times 10^{-4}(X^3) + 0.02456(X^2) + 0.3361(X) - 5.359, \quad (6)$$

$$PN60 = -5.77 \times 10^{-5}(X^3) + 0.01044X^2) + 0.3002(X) - 4516, \quad (7)$$



(A) (B)

Figure 4 Average plant height recorded at regular time intervals throughout the growth period for the variety BPT5204 (A) and NDLR07 (B)

$$PNC = -7.317 \times 10^{-5}(X^3) + 0.008127(X^2) + 0.9145(X) - 4.048, \quad (8)$$

Where PN20, PN40, PN60, and PNC are the plant heights of NT20, NT40, NT60, and NC; X is DAS. The R^2 values were 0.9964, 0.9838, 0.9972, and 0.9945; while RMSE values were 2.3143, 4.9411, 1.6337, and 2.6947, respectively for eq. 5, 6, 7, and 8. The order of plant height at the end of the harvest period was NT20>NT40>NC>NT60 (Figure 4B). Compared to the control group, the growth rate of NT20 was 8.1% higher than that of NT40 1.1% (lower) and that of NT60 3.5% (lower). The highest peak growth rate was seen for NT20 at 72 DAS (Figure 5B). The growth rate trends of NT20 and NT40 were similar, while those of NT60 and NC were also found similar. After the induced drought period, the treatment groups continued to show an increasing growth rate, while the decreasing trend of NC growth rate continued even with adequate water supply. NT20 showed 5 peaks at 16-24 days interval; NT40 showed 6 peaks with a wide gap of 24 days between the first 2 peaks, and then reaching peaks at 16 days interval for the rest; NT60 showed 6 peaks too with similar intervals as NT40; NC showed 3 peaks at 16 to 24 days interval and gradually declined after the 3rd peak.

In both seed types (BPT5204 and NDLR07), the least growth was seen in groups with a 60% deficit supply of water, while the highest growth was seen in the groups with a 20% deficit supply of water. The control group had only 3 peaks as opposed to 4 to 6 peaks in the treatment groups, after which the control group only showed a decline in growth rate as opposed to the treatment groups which continued to show peaks and increased growth rate. During the induced drought period, in both varieties of rice, the growth rate was not significantly affected. There was even an increase in the growth rate for some cases (BT40 and NT20).

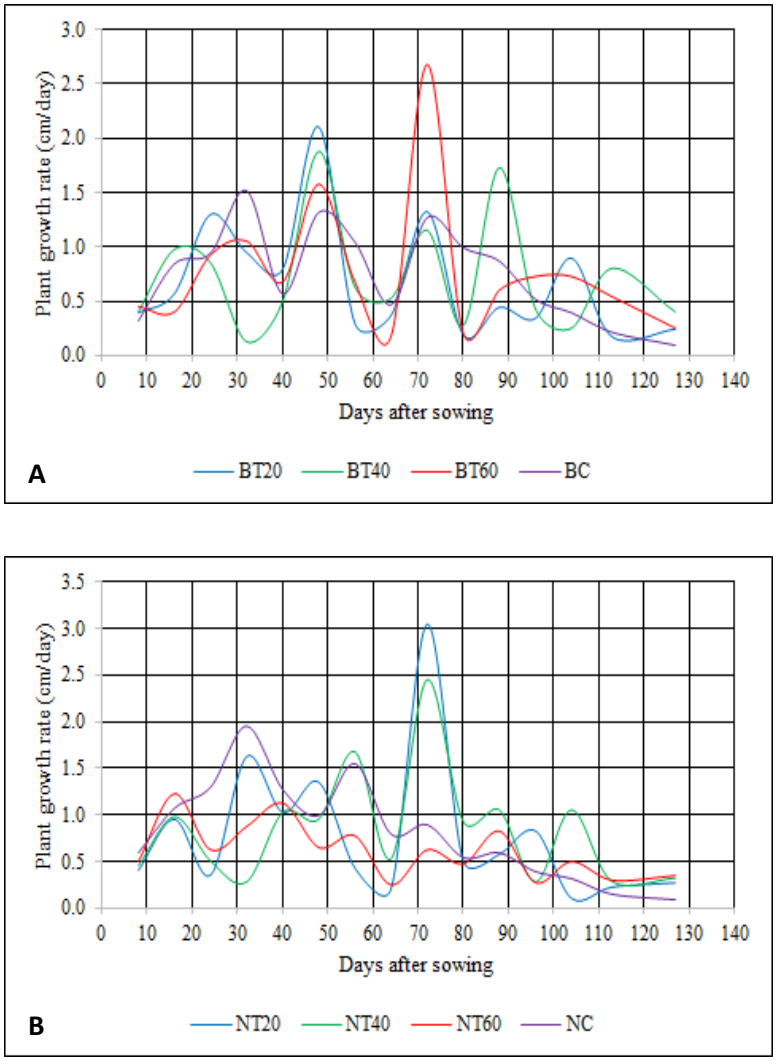


Figure 5 Plant growth rate expressed in cm/day, for the duration of induced drought in BPT5204 (A) and NDLR07 (B) for treatment groups.

4 Discussion

NDLR07 (NT20) performed the best among all experimental groups, with a growth of up to 105.2 cm at 127 DAS. The high growth could be because of NDLR07's adaptability to drought (Jayalakshmi et al., 2020). It is also evident that drought conditions had some effect on the growth rate in the groups treated with hydrogel. Even under a 60% deficit of water supply, with an induced drought period of 14 days, the survival of paddy crops was not affected. The crop growth rate towards the end of the reproductive stage directly impacts the yield as it involves the growth of spikelets (Takai et al., 2006). Considering the same stage in the treatment groups and relating crop growth rate to the plant height growth rate, the rate of growth continues to increase instead of a decrease in control groups. This suggests that treatment with hydrogel could increase yield, compensating for damage (if any) from a lack of water. Sen et al. (2019), showed that hydrogel application helped rice crops survive drought for longer durations. This was attributed to better root growth conditions due to hydrogel application. The formation of a root-soil-water matrix at the root zone, during induced drought, suggested that the roots are better preserved with a continued supply of water (Agaba et al., 2011). A similar study by Kurrey et al. (2018) reported concurrent results when the root system is under shock from drought, stomatal cells close, leading to a decreased growth rate (Kim et al., 2020). The presence of hydrogel prevents this as the roots are protected from moisture stress. Under normal conditions, the yield of crops treated with hydrogel increases significantly (Roy et al., 2019). In a climate change scenario where rice production is affected adversely, hydrogel application along with other mitigation methods could contribute to a sustainable support system to combat drought events (Soundharajan & Sudheer, 2009; Uga et al., 2013; Li et al., 2015).

Conclusion

Insights were derived in the present study on the potential positive effects of Hydrogel application as a drought mitigation method. The hydrogel can amend the root-soil-water relationship in crop systems to enhance crop growth. The use of NDLR07 as a drought-resistant crop amended with hydrogel would prevent damage and loss from drought conditions. BPT5204 variety has also shown resistance to drought conditions when amended with hydrogel. The increase in productivity would help ensure sustainability, thereby allowing the farmers to fetch benefits. In the present study, the productivity of crops based on plant height has been established with mathematical relations. Though the third-degree polynomial matches with a high correlation, subsequent research should be done using parameters such as biomass, water schedules, temperature, and humidity to deepen the understanding of hydrogel influences on crop growth.

Acknowledgements

We are grateful to CHRIST (Deemed to be University) for supporting the study. The support given by Krishi Vigyan Kendra through providing facilities for field experimental setup is greatly acknowledged.

Conflict of Interest

The authors state that they have no conflict of interest.

References

Agaba H, Orikiriza LJ, Obua J, Kabasa JD, Worbes M, Hüttermann A (2011) Hydrogel amendment to sandy soil reduces irrigation frequency and improves the biomass of Agrostis stolonifera. Agricultural Sciences 2(04): 544.

Ahmed EM (2015) Hydrogel: Preparation, characterization, and applications: A review. Journal of Advanced Research 6(2):105-121.

Chun JA, Li S, Wang Q, Lee WS, et al. (2016) Assessing rice productivity and adaptation strategies for Southeast Asia under climate change through multi-scale crop modeling. Agricultural Systems 143:14-21.

Guilherme MR, Aouada FA, Fajardo AR, Martins AF, et al. (2015) Superabsorbent hydrogels based on polysaccharides for application in agriculture as soil conditioner and nutrient carrier: A review. European Polymer Journal 72: 365-385.

IPCC special report (2019) Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Retrieve from https://reliefweb.int/sites/reliefweb.int/files/resources/4.-SPM_Approved_Microsite_FINAL.pdf.

Jayalakshmi M, Babu GP, Chaithanya BH (2020) On Farm Testing of Rice Variety NDLR-7 as an Alternative to Traditionally Grown BPT-5204 in Kurnool District of Andhra Pradesh. Agricultural Science Digest (40):392-395.

Kalhapure A, Kumar R, Singh VP, Pandey DS (2016) Hydrogels: a boon for increasing agricultural productivity in water-stressed environment. Current Science 111 (11): 1773-1779.

Kalyanasundaram D, Arthi E, Kumar KS, Sri SH (2021) Yield maximization of direct sown rice (*Oryza sativa* l.) under water constraint situation. Journal of Applied and Natural Science 13(1): 373-376.

Kim Y, Chung YS, Lee E, Tripathi P, Heo S, Kim KH (2020) Root response to drought stress in rice (Oryza sativa L.). International Journal of Molecular Sciences 21(4):1513.

Kurrey D, Singh RK, Rajput RS (2018) Effect of Hydrogel and *Trichoderma* on root growth and water productivity in rice varieties under Rainfed Conditions. Research Journal of Agricultural Sciences 9: 210-212.

Lather VS, Ashwani K, Chopra NK, Choudhary D, Yadav RN, Seth R (2015) Novel herbal hydrogel Tragacanth-Katira gel and farmer's friendly seed priming-hydrogel coating technology for water saving, making agriculture sustainable and resilient to climatic variability. International Journal of Tropical Agriculture 33(2): 1167-1171.

Li T, Angeles O, Radanielson A, Marcaida M, Manalo E (2015) Drought stress impacts of climate change on rainfed rice in South Asia. Climatic Change 133(4): 709-720.

Neethu TM, Dubey PK, Kaswala AR (2018) Prospects and applications of hydrogel technology in agriculture. International Journal of Current Microbiology and Applied Sciences 7(5): 3155-3162.

Parthasarathi T, Vanitha K, Mohandass S, Vered E (2018) Evaluation of drip irrigation system for water productivity and yield of rice. Agronomy Journal 110(6): 2378-2389.

Pirmoradian N, Sepaskhah A, Maftoun M (2004) Deficit irrigation and nitrogen effects on nitrogen-use efficiency and grain protein of rice. Agronomie 24(3):143-153.

Prakash S, Vasudevan S, Banerjee A, Joe AC, Reddy GKNG, Mani SK (2021) Sustainable water consumption of rice (*Oryza sativa* L.) as influenced by superabsorbent polymer in water stressed conditions. International Journal of Modern Agriculture 10(1): 857-866.

Rehman A, Ahmad R, Safdar M (2011) Effect of hydrogel on the performance of aerobic rice sown under different techniques. Plant, Soil and Environment 57(7): 321-325.

Roy T, Kumar S, Chand L, Kadam DM, et al. (2019) Impact of Pusa hydrogel application on yield and productivity of rainfed wheat in North West Himalayan region. Current Science 116(7): 1246-1251.

Sen A, Singh RK, Yadaw D, Kumari P, et al. (2019) Effect of *Trichoderma* and hydrogel on growth, yield and yield attributes of direct seeded rice (*Oryza sativa*) under rainfed condition. Indian Journal of Agricultural Sciences 89(2): 333-8.

Soundharajan B, Sudheer KP (2009) Deficit irrigation management for rice using crop growth simulation model in an optimization framework. Paddy and Water Environment 7(2):135-149.

Sudharani JS, Aruna K, Ramakrishna Babu A (2019) Drum Seeder a Promising Low-Cost Technology in Rice Production System for Small and Marginal Farmers of Mahabubnagar District, India. International Journal of Current Microbiology and Applied Sciences 8(2):784-788.

Takai T, Matsuura S, Nishio T, Ohsumi A, Shiraiwa T, Horie T (2006) Rice yield potential is closely related to crop growth rate during late reproductive period. Field Crops Research 96(2-3): 328-335.

Uga Y, Sugimoto K, Ogawa S, Rane J, et al. (2013) Control of root system architecture by DEEPER ROOTING 1 increases rice yield under drought conditions. Nature Genetics 45(9):1097-1102.